Incorporation and Control of Strontium, Cesium, and Iodine Secretion in Milk

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"Animal Metabolism of Radionuclides"

OCD REVIEW NOTICE

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Abstract

Experimental verificatic a method for the prediction of the total intake commitment of ^{137}Cs, ^{90}Sr and ^{131}I from milk by average members of a human population following deposition of fallout on pasture is presented. The method has been expanded to account for extended and multiple depositions and delays in pasturing cows. As a dietary countermeasure against radiostrontium secretion into milk sodium alginate was about twice as effective as aluminum phosphate gel. Ferric ferrocyanide fed to cows produced over a 90% reduction in ^{137}Cs in milk.

II. Introduction

Following a nuclear event which contaminates the environment with radioactive fallout the major source of ingested ^{131}I, ^{90}Sr, and ^{137}Cs for large segments of the human population is via milk. In dealing with the problems which would arise as a result of such an event two factors must be considered. First, a reliable estimate of the total intake commitment of the radionuclides by an average member of the population should be obtainable. Secondly, if the projected commitments are adjudged greater than acceptable, it is important to have available a selection of countermeasures, each of which would reduce the amounts ingested by humans to an acceptable level.

A method for the prediction of the total intake commitment of ^{137}Cs, ^{131}I and ^{90}Sr from milk by average members of a human population following a single rapid deposition of radioactive fallout on pasture has been developed at this laboratory. The method has been shown to be independent of level of pasture contamination, solubility of radionuclides in the fallout, and dietary factors such as level of stable calcium in the ration of cows. In the study reported herein these mathematical models have been expanded to include situations (1) where fallout accumulation on pasture is not very rapid but is deposited at an exponential rate and (2) where there are two or more incidents which cause pasture contamination at different times. Feeding experiments were carried out to check on the mathematical models.

Should the amounts of radionuclides in milk reach levels which, when projected to the total intake commitment of a population, are above tolerable limits countermeasures would have to be taken. These could take the form of removing the contaminated milk from diets, decontaminating milk through a chemical process, feeding cows uncontaminated feed where available, or feeding some dietary substance to cows which would reduce radionuclide levels in milk. While the first three of these methods can be accounted for in the model, little has been reported on the effectiveness in cattle of certain dietary countermeasures. This report describes further efforts in this area.

III. Use of Ferric Ferrocyanide as a Remedial Measure Against ^{137}Cs

A. Literature

Because ^{137}Cs must be considered as a potentially hazardous fission product considerable amount of work has been done to decrease absorption and/or enhance excretion. These efforts have by and large led to ambiguous results. However, the feeding of ferric ferrocyanide (Prussian Blue) shows promise. Nigrović (1963, 1965) observed that oral administration of ferric ferrocyanide reduced retention of orally consumed ^{137}Cs by as much as 99% in rats. In addition, the biological half time of parenterally administered ^{137}Cs has been reduced by approximately 50 percent when this material was fed rats (Nigrović, Bohne and Madshus, 1966). These European workers also demonstrated a reduction by nearly 40% in the biological half-life of ^{137}Cs in 7-8 kg. dogs fed 1.5 to 3 grams of ferric ferrocyanide daily (Madshus, Stromme, Bohne, and Nigrović, 1966). Recently Madshus and Stromme (1968) personally consumed 3 grams of ferric ferrocyanide per day and obtained a reduction in the biological half life of ^{137}Cs to one third of its original value. The consumption of ferric ferrocyanide at this level did not reduce ^{137}Cs absorption however.

Havlicek, et. al. (1967) have shown that ferrocyanides are effective in goats as well as rats. Havlicek (1968) also showed that ferric ferrocyanide was effective in the pregnant and in the lactating rat.

No reports of toxic or deleterious side effects of ferric ferrocyanide ingestion have been seen. Richmond (1968) reports that potassium and sodium stores do not appear to be affected by ferric ferrocyanide.

Investigations on the effects of ferric ferrocyanide at this laboratory, initiated prior to the publication of several of the previous references, have employed rats and dairy cows as experimental animals. The rat experiment was conducted for the purpose of (1) confirming observations of Nigrović and (2) being sure that the ferric ferrocyanide to be used in cattle experiments was potent. The cattle experiments were carried out to determine the effectiveness of this product in reducing radiocesium levels in milk. The ferric ferrocyanide used in both the rat and cattle studies was obtained from Harleco (Hartman-Leddon Co., Philadelphia, Pa.).

B. Feeding of Ferric Ferrocyanide to Rats

Ferric ferrocyanide was included in the ration of two groups of rats at rates of 0.5% and 1.0% by weight. A control group received no ferric ferrocyanide. Each group consisted of four 170-gram rats. Two days after placing the rats on this supplemented ration all rats were given ^{134}Cs via a stomach tube. The rats were counted in a small whole-body counter immediately after dosing and again at 5, 8 and 11 days. Percentage retention data follow:

Table 1. Whole-body retention of ^{134}Cs by rats fed ferric ferrocyanide.

Group	5 Days	8 Days	11 Days
Control	54.7%	43.0%	35.4%
0.5% F.F.	3.2% (5.8)*	1.9% (4.4)	1.3% (3.7)
1.0% F.F.	0.79% (1.4)	0.50% (1.2)	0.34% (1.0)

* Values in parentheses express retention as percentages of control data at the given time periods.

A marked decrease in retention at day 5 was observed when either level of ferric ferrocyanide was fed. Although this experiment does not differentiate between effects on absorption and turnover of absorbed ^{134}Cs between day 0 and day 5 it would seem that absorption was reduced. Turnover rates between days 5 and 11, a period prior to which absorption should have been completed, were doubled when ferric ferrocyanide was fed. The $t_{1/2}$ during this period averaged 4.7 days for rats receiving either level of ferric ferrocyanide as compared to 9.2 days for the control rats. The magnitude of the effects observed are very similar to those seen by Nigrović.

C. Feeding of Ferric Ferrocyanide to Cattle

Cattle feeding experiments were conducted to gather information on the influence of (1) level of ingestion, (2) time of ingestion and (3) a single versus daily ingestion of ferric ferrocyanide upon the secretion of radiocesium into milk.

Table 2 summarizes the design of the experiments performed. Two cows were fed a single supplement of 50 grams of ferric ferrocyanide at the same feeding in which a single dose of radiocesium was administered. In other experiments these two cows plus two additional cows were fed 25 grams of ferric ferrocyanide in each of two feedings daily (50 grams per day) for periods of up to 17 days. In the latter experiments radioisotopes of cesium were fed 24 and 8 hours before and at 0 and 48 hours after the feeding of ferric ferrocyanide was initiated. In two other feeding trials one of these cows was supplemented with ferric ferrocyanide daily at rates of 25 grams per day and 10 grams per day. All cows were used in one or more control periods in which single doses of radiocesium were administered with no supplement of ferric ferrocyanide.

Table 2. Experiments conducted in which cattle were fed ferric ferrocyanide. Values given are cow identity numbers.

Ferric Ferrocyanide Feeding Schedule	Radiocesium Dosing Time (Hours)	Grams Ferric Ferrocyanide Per Day		
		50	25	10
Single Dose	0*	174 177		
Dosed Twice Daily	-24	177		
	- 8	177		
	0	177 174 175	174	174
	+48	177 174 176 175	174	174

* Time at which a single dose of radiocesium was administered relative to the initiation of feeding of ferric ferrocyanide. Negative times indicate radiocesium given before ferric ferrocyanide and positive times indicate radiocesium given after the initiation of feeding of ferric ferrocyanide.

The ferric ferrocyanide used in these studies was administered by hand mixing a weighed allotment into the grain ration of each cow for feeding. It was found that mixing in a mechanical mixer left a hard-to-remove stain in the stainless steel mixing tub. Radiocesium used was ^{137}Cs and/or ^{134}Cs in the chloride form and was dried on the inside of gelatine capsules. Administration was orally via a balling gun.

Quart milk samples were taken at each milking during the first few days of each experiment and at morning milkings only thereafter. The samples were assayed for ^{134}Cs and ^{137}Cs in a large sample scintillation counter equipped with two 5 x 4 inch NaI (Th) crystals (Nuclear Chicago - Tobar) which was attached to a 3-channel analyzer-scaler.

1. General Observations

The feeding of 50 grams of ferric ferrocyanide per day to three cows reduced radiocesium levels in milk by 95 to 98% with an average reduction of 96%. The variation between cows was in part due to the size differences among the cows. A Jersey weighing 900 pounds had the greatest reduction in radiocesium output whereas the cow which showed the least effect was a Holstein weighing 1450 pounds.

As may be seen in Figures 1 through 4, the feeding of ferric ferrocyanide not only reduced the peak radiocesium concentration in milk but also increased the slope of the transfer function of cesium into milk. The concentrations of radiocesium in milk following the feeding of 50 grams of ferric ferrocyanide per day were 5.2 and 2.6% of levels observed during the control periods on days 1 and 7 respectively. The slope of the transfer function may also be increased several months after the ingestion of radiocesium by the cow. Starting at 80 days after dosing with ^{134}Cs Cow 174 was fed 50 grams of ferric ferrocyanide per day. The slope of the milk concentration curve changed from a half-time of 27 days to a half-time of 5.5 days.

The data obtained in these experiments are summarized in Tables A-2 through A-5. In addition to the actual concentration of radiocesium measured in milk at particular times, the cumulative amounts of radiocesium secreted into milk up to given times has been calculated. While these values are of interest for comparative purposes they are influenced by the amount of milk produced daily which is in turn variable due to factors such as stage of lactation, stage of gestation, temperature and other factors. A third quantity has been calculated which, it is believed, is a better index of the effectiveness of a particular countermeasure. This quantity is the total radiocesium secreted from the time of dosing to a given day divided by the average daily milk production during the period ($\Sigma\%/(1/\text{day})$). This quantity, which will hereafter be referred to as the "accumulated concentration", is an indication of the concentration to be expected if the cow was fed the same dose of radiocesium daily. The 7-day accumulated concentrations of radiocesium will be utilized for comparisons between treatments. This corresponds to about 72% of the expected steady state radiocesium concentrations in milk after prolonged daily dosing with the radionuclide (Comar _et al_. 1967).

2. Level of Ferric Ferrocyanide Feeding

A Jersey cow (174) was fed ferric ferrocyanide at levels of 50, 25 and 10 grams per day. One radioisotope of cesium was fed when the ferric ferrocyanide supplementation was started and another isotope was fed two days later. These data are presented in Table A-2 and Figures 1 and 2. In Table 3 the effects of each treatment are expressed as a percentage of the corresponding values obtained during the control period.

Table 3. Levels of radiocesium secreted into milk of Cow 174 when ferric ferrocyanide was fed expressed as percentages of levels observed during the control period.

Time of Radiocesium Administration	Amount of Ferric Ferrocyanide Fed (Grams/Day)	Peak Concentration	7-Day Secretion	7-Day Accumulated Concentration
T = 0 Hours	50	3.8	2.0	2.8
	25	6.0	3.2	4.5
	10	11.1	6.4	8.8
T = 48 Hours	50	1.4	0.8	1.2
	25	2.8	1.5	2.1
	10	7.4	4.2	5.8

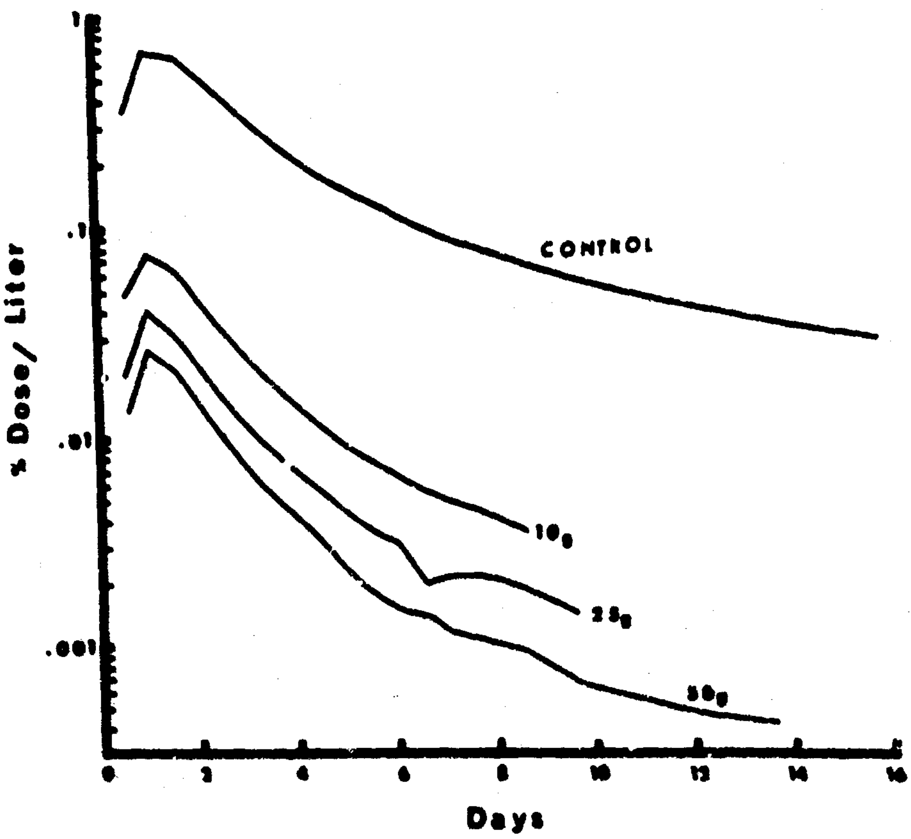

Figure 1. Concentrations of radiocesium in the milk of Cow 174 following single doses of radiocesium and daily supplements of 10, 25 or 50 grams of ferric ferrocyanide started at the time of radiocesium administration (T=0).

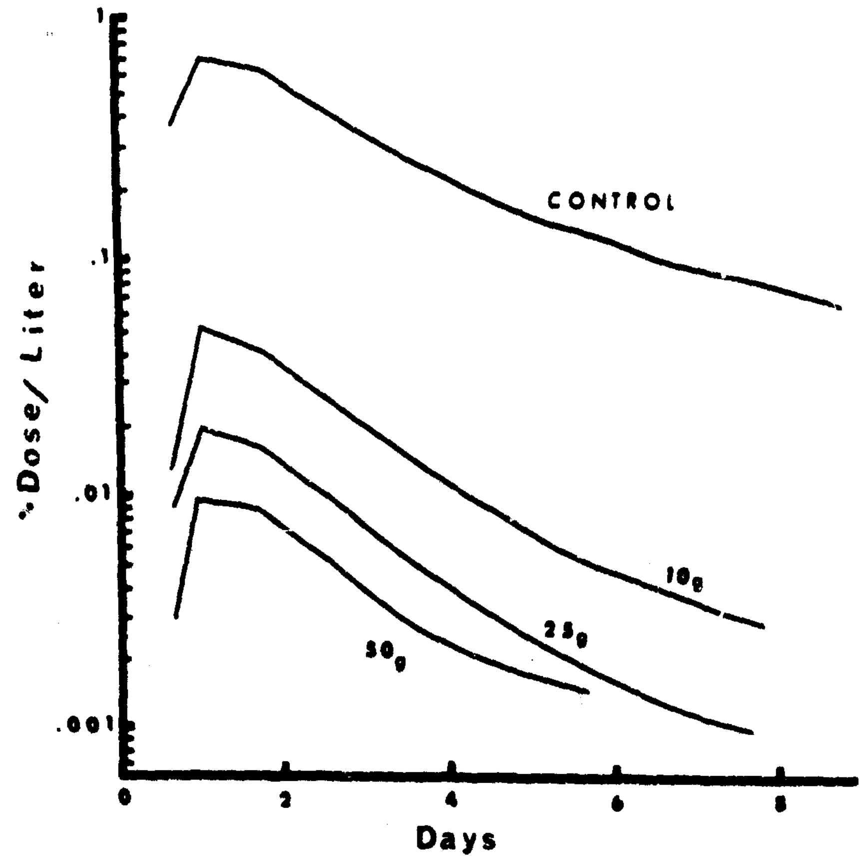

Figure 2. Concentrations of radiocesium in the milk of Cow 174 following single doses of radiocesium and daily supplements of 10, 25 or 50 grams of ferric ferrocyanide started 48 hours before the time of radiocesium administration (T-48).

A straight line relationship was observed between the level at which the ferric ferrocyanide was fed and the inverse of the percentage change in radiocesium secretion due to changing the ferric ferrocyanide supplementation level. When T = 48 hours an increase by a factor of two in the level of feeding of ferric ferrocyanide decreased the radiocesium levels in milk by one-half. When ferric ferrocyanide feeding was started at the same time as the radiocesium was administered, T = 0, doubling of the supplementation rate reduced radiocesium levels in milk by one-third. It would appear that in the range of supplementation studied, 10 to 50 grams per day, the maximum effect of feeding ferric ferrocyanide has not been reached and that the effect obtained is proportional to the supplementation rate.

3. Time of Ferric Ferrocyanide Supplementation

Cow 177 was fed single doses of radiocesium at four time periods relative to the initiation of feeding of ferric ferrocyanide: 24 and 8 hours before and 0 and 48 hours after 50 grams per day of ferric ferrocyanide supplementation was started. This data is presented in Table A-5 and Figure 3. The levels of secretion of radiocesium in these experiments expressed as percentages of the levels observed during the control period are listed in Table 4.

Table 4. Levels of radiocesium in the milk of Cow 177 when ferric ferrocyanide supplementation (50 grams/day) was initiated at four time periods expressed as percentages of levels observed during the control period.

Time of Radiocesium Administration (Hours)*	Peak Concentration	7-Day Secretion	7-Day Accumulated Concentration
T = -24	88.8	58.1	57.8
T = - 8	42.5	28.3	27.5
T = 0	6.5	5.0	4.7
T = 48	4.2	4.1	3.6

* Negative times indicate radiocesium given before ferric ferrocyanide and postive times indicate radiocesium given after the initiation of feeding of ferric ferrocyanide.

When compared to the case when ferric ferrocyanide supplementation is initiated at the time radiocesium is administered (T = 0), a delay of 8 or 24 hours in the feeding of ferric ferrocyanide results in 6 or 12 times as much radiocesium in the milk during the following seven days. When ferric ferrocyanide was administered two days before radiocesium ingestion the 7-day accumulated concentration was 76% of that obtained when T = 0. If data from two additional cows (174 and 175) are included in the latter comparison the 3-cow average is 64% rather than 76%.

As could be expected, for maximum effectiveness ferric ferrocyanide must be present when radiocesium is consumed, however it is important to note that there is a significant reduction in milk contamination even when it is fed one day after the ingestion of radiocesium. Even though the peak concentration of radiocesium was reached before the ferric ferrocyanide was fed the 7-day output of the radionuclide in milk was down to 58% of that obtained during the control period.

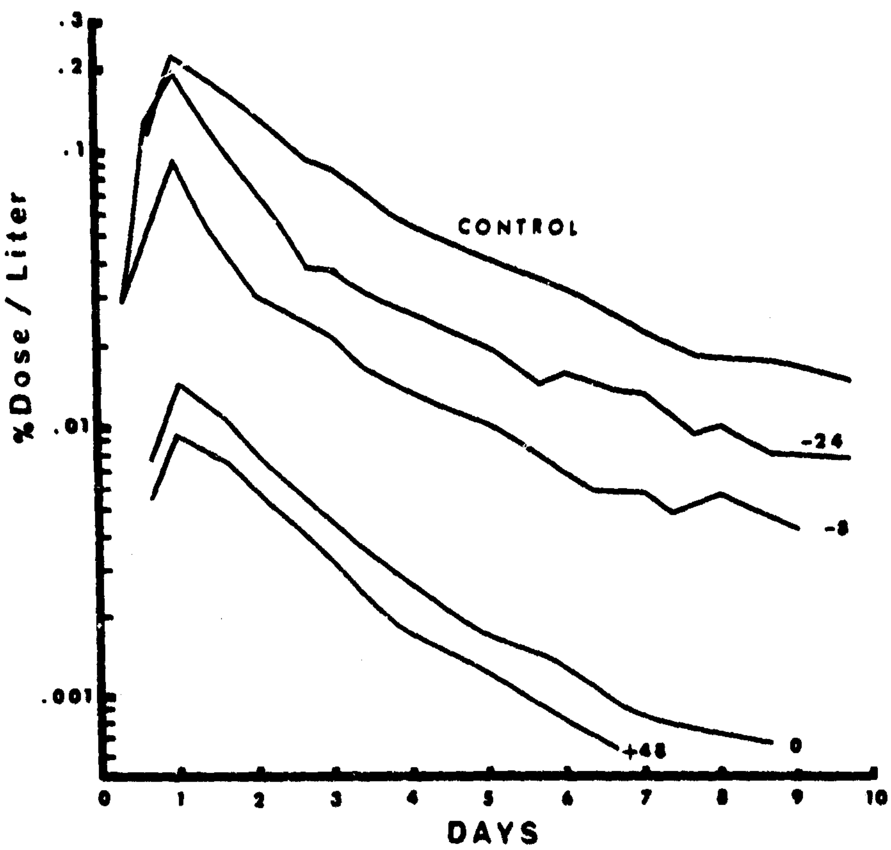

Figure 3. Concentrations of radiocesium in the milk of Cow 177 when single doses of radiocesium was given 24 and 8 hours before and 0 and 48 hours after the initiation of supplementation with ferric ferrocyanide at a rate of 50 grams per day.

4. Single vs. Daily Supplementation

Data for making comparisons between the effectiveness of single vs. daily supplements of ferric ferrocyanide are presented in Tables A-2 and A-5 and plotted in Figure 4. Inasmuch as 50 grams of this material was fed with the radiocesium in the case of the single-supplement experiment and 25 grams was fed with the radioisotope in the case of the twice-daily supplementation routine (followed by another 25 grams at the next feeding) it is not surprising that the concentration of radiocesium in milk at the first milking was about twice as high in the daily supplemented treatment as in the single supplement treatment. However, when 50 grams per day, 25 grams per feeding, was fed starting two days prior to the administration of radiocesium no great difference in the concentration of radiocesium in the first milking was observed.

The shape of the secretion curve following a single feeding of ferric ferrocyanide was quite different than that observed with the daily feeding of the supplement. The peak radionuclide level in milk appeared $1\frac{1}{2}$ to 2 days after ingestion of the radiocesium dose rather than at about 1 day as seen in control period and when daily supplementation was provided. Also, after about 5 days the curve paralleled the control curve quite closely.

Comparisons between the control periods and the experimental periods were made and are shown in Table 5.

Table 5. Levels of radiocesium secreted into milk when ferric ferrocyanide was fed in single feedings or in daily feedings expressed as percentages of levels observed during control periods.

Treatment	Cow	Peak Concentration	7-Day Secretion	7-Day Accumulated Concentration
Single Feeding	174	1.71	1.77	2.52
50 grams	177*	4.85	8.99	6.97
T = 0. hrs.	Mean	3.28	5.38	4.74
Daily Feeding	174	3.38	1.99	2.76
50 grams/Day	177	6.51	5.01	4.67
T = 0. hrs.	Mean	5.17	3.50	3.71

* Fed in combination with sodium alginate and a hi-calcium diet. See section IV.

The 7-day and 14-day accumulated concentrations of radiocesium in milk were on the average 20% and 36% higher respectively for the single supplementation than when daily feedings were started at the same time as the cows were dosed with radiocesium.

5. Projection To A Pasture Situation

The effects of ferric ferrocyanide can be partitioned into two parts: (1) a reduction in the availability of the ingested radiocesium for absorption and (2) an enhanced turnover of previously absorbed radiocesium resulting in a decrease in the level of radiocesium in circulating fluids and in milk. In order to mathematically estimate the effectiveness of feeding ferric ferrocya-

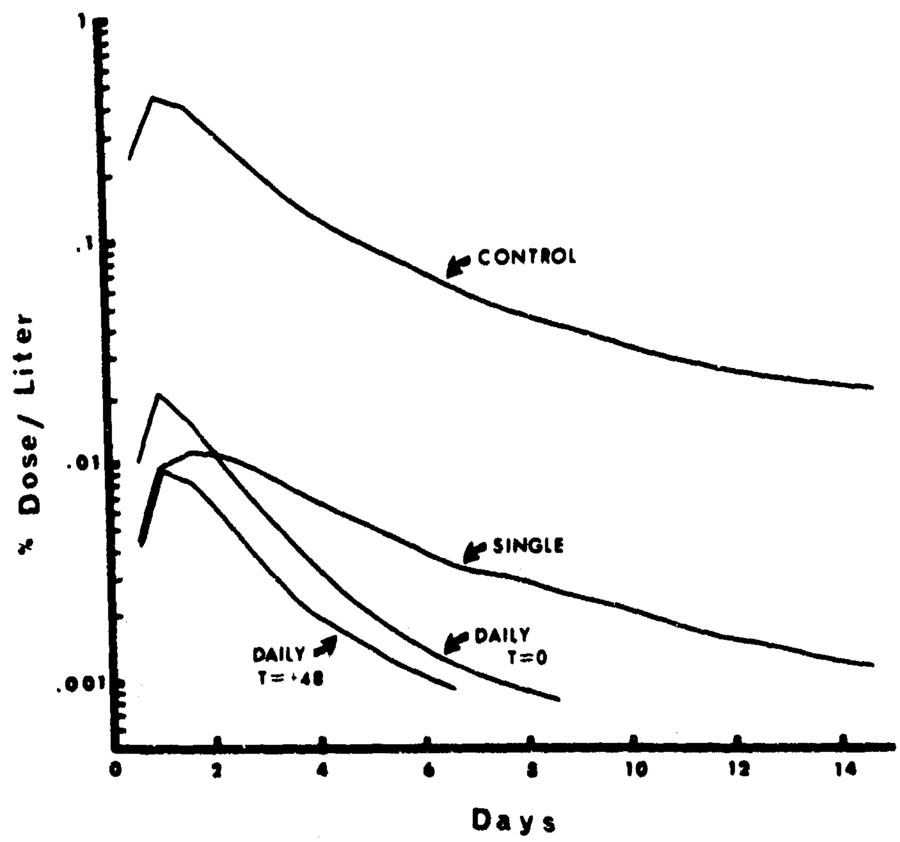

Figure 4. Comparison of effects of a single feeding of 50 grams of ferric ferrocyanide and daily supplements of 50 grams/day of ferric ferrocyanide upon concentrations of radiocesium in milk. (Average of Cows 174 and 177).

nide in a situation where cattle are continuously grazing on contaminated pasture, it was necessary to separate these effects. From a comparison of the concentrations of radiocesium in the first days milk samples following a single dose of radiocesium at various time periods relative to the initiation of feeding of 50 grams of ferric ferrocyanide per day an empirical equation for changes in biological availability of the cesium was derived: Percent Availability $= 95e^{-10(T+.43)} + 5$. The quantity "T" is the time between the initiation of feeding of ferric ferrocyanide and the consumption of contaminated feed. The function along with factors for radionuclide decay and for the rate of loss of radiocesium from grass due to processes other than decay is applied to adjust the intake rate in the equations for predicting radiocesium levels in milk as described in our previous reports (Lengemann _et al._, 1968, Comar _et al._, 1967).

To estimate enhancement of turnover rates of absorbed radiocesium the slopes of the milk radiocesium secretion curves for the control period and for periods when ferric ferrocyanide was fed were compared. The function, Cs* Concentration (With F.F.) = Cs* Concentration (W/O F. F.) $\cdot$ $(0.68e^{-42T} + 0.32)$, was applied to adjust the predicted concentrations of radiocesium in milk from cows grazing on contaminated pasture.

A comparison of levels of ^{137}Cs estimated to be in milk from cows feeding on contaminated pasture with and without countermeasures being applied are plotted in Figure 5. Calculations for these plots are based upon conditions of a single rapid deposition of fallout upon pasture with a half-time of removal from grass by processes other than radioactive decay of 14 days and utilizes the transfer function described in our previous report, TRC-67-33 (1967). The concentrations of ^{137}Cs are expressed as percentages of the initial intake rate (units activity/day) by the cows per liter of milk. The upper curve shows the concentration of ^{137}Cs that would be found in milk from cows grazing on pasture following a contaminating event. The other curves display the expected concentrations if after 1 or 8 days of grazing on the contaminated pasture the cows were (a) fed 50 grams of ferric ferrocyanide per day, (b) removed from the pasture and fed clean feed or (c) fed clean feed plus 50 grams of ferric ferrocyanide per day.

For immediate results the feeding of ferric ferrocyanide is somewhat more effective than placing the cows on clean feed. This is the case even though the cows will continue to absorb about 5 percent of the ingested ^{137}Cs because (1) much of the ^{137}Cs in the gastrointestinal tract at the time of ingestion of the ferric ferrocyanide will be rendered unavailable for absorption and (2) the turnover of the previously absorbed ^{137}Cs will be enhanced.

A comparison of the overall effectiveness of countermeasures against ^{137}Cs is shown in Figure 6. The amount of ^{137}Cs from milk consumed by man when a countermeasure is instituted expressed as a percentage of the total projected intake if no action was taken is plotted against the time after deposition when protective action is taken.

In comparing the countermeasures it is obvious that the complete elimination of contaminated milk from the diet is the most effective measure. However, the advantage of the clean feed or the ferric ferrocyanide methods is that they have little effect upon the normal food distribution pathways or upon the food habits of the consumers. When ferric ferrocyanide feeding is instituted

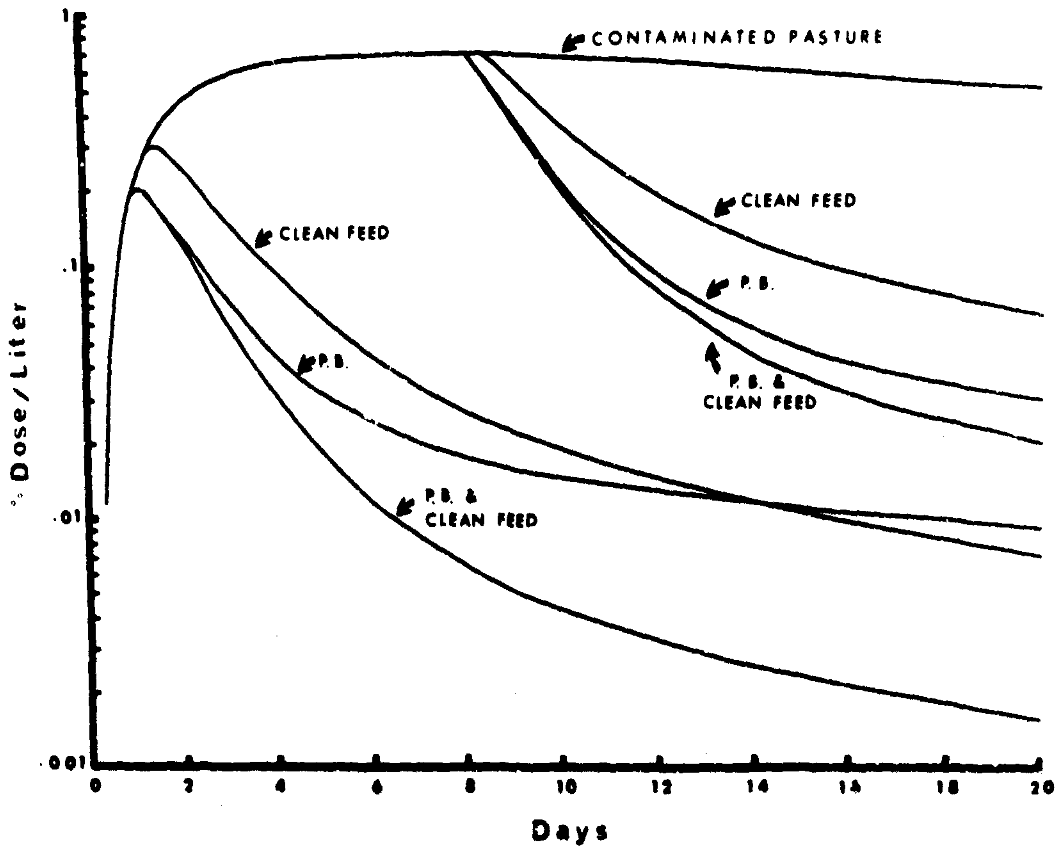

Figure 5. Concentrations of ^{137}Cs in milk of cows grazing on contaminated pasture with or without countermeasures being taken. Plots are for the feeding of ferric ferrocyanide (P.B.) and/or uncontaminated feed beginning at 1 or 8 days after the deposition of fall-out.

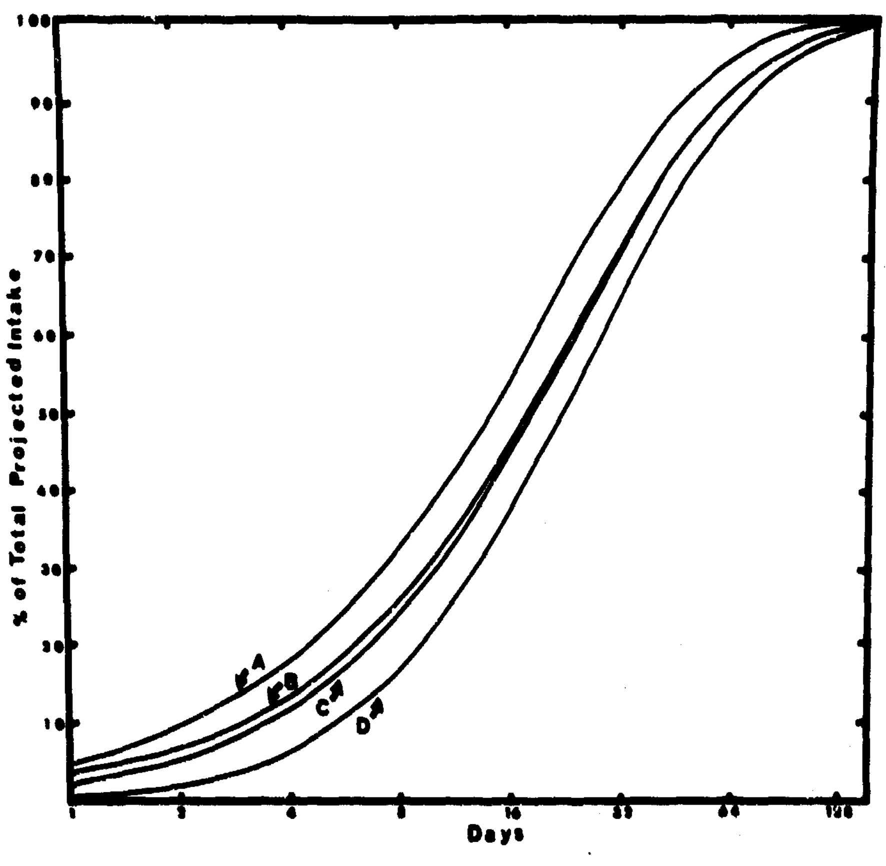

Figure 6. Effectiveness of countermeasures against radiocesium plotted against days of intake of contaminated milk by man before protective action is operative. Countermeasures are (A) placing cows on clean feed, (B) feeding ferric ferrocyanide, (C) placing cows on clean feed plus feeding ferric ferrocyanide, and (D) excluding contaminated milk from the human diet.

between days 1 and 2 the total intake by man from milk is about 71 percent of that consumed if the cows were placed upon clean feed instead. While this difference could be of significance it would appear that the most practical time to feed ferric ferrocyanide would be when a source of clean feed was not available.

IV. Dietary Supplements as Remedial Measures Against ^{90}Sr

A. Literature

1. Sodium Alginate

The selective inhibition of strontium absorption following the administration of sodium alginate to rats was first reported by Skoryna and colleagues from Canada (1964, 1965) when they observed a 50 to 80% reduction of radiostrontium absorption with no significant reduction in calcium absorption. Similar inhibition of radiostrontium absorption by sodium alginate has since been observed in rats and humans by others.

Commercially available alginates are salts of naturally occurring compound polymers of mannuronic and guluronic acids (alginic acid) which are extracted from brown seaweed (Phaeophyceae). Sodium alginate is water soluble and from a practical standpoint it is important to note that it is already widely used in the food industries including incorporation into products such as ice cream, jellies, jam, puddings, etc., as an emulsifying and stabilizing agent.

Alginates with a high guluronic acid content such as those derived from certain Laminaria species appear to be most effective. When such products are fed to rats at the rate of 10% of their diet typical reductions in strontium absorption range about 75 to 80%. whereas changes in radiocalcium absorption have varied between -29% and +33% (Harrison et al. 1966, Patrick et al. 1967, Kostial et al. 1967). Hesp and Ramsbottom (1965) and Sutton (1967) have reported a reduction in radiostrontium uptake of 64 to 89 percent when 10 grams of sodium alginate derived from Laminaria species was fed to adult humans who had fasted overnight. When sodium alginate derived from Macrocystis pyrifera, which has a lower guluronic acid content, was administered as a jelly to human adults strontium retention was reduced by about 56% whereas radiocalcium retention was reduced by only 18% (Harrison et al. 1966).

Humphreys (1967) and Tanaka (1968) have described alginate derivatives, some of which appear to be more effective than sodium alginate. A derivative containing 97% L-guluronic acid when fed to rats at a rate of 10% of their ration reduced radiostrontium absorption by 85% with no inhibition of calcium absorption (Patrick et al., 1967) and when consumed by humans a reduction in the absorption of ^{87m}Sr by 83 to 87% was indicated (Sutton, 1967). Tanaka (1968) after studying several degradation products of alginates concluded that their strontium binding capacities in vivo are only partly dependent upon the presence of a high guluronic acid content.

In a very recent study (Carr et al., 1968) the absorption of ^{47}Ca and ^{85}Sr was studied in 4 human volunteers with and without sodium alginate; the alginate decreased the retention of ^{85}Sr by 70% and ^{47}Ca by 7%. The stable elements Na, K, Mg and P were also studied and no change was observed in their excretion

pattern or plasma level. There has been some indication that alginate will interfere with iron metabolism because of its strong binding potential for ferric ion but this issue is still equivocal.

Only two reports have been found of use of sodium alginate from animals. Milin and Anderson (1969) and Colvin et al. (1967) found their alginates to be ineffective in pigs and chickens respectively.

2. Aluminum Phosphate Gel

Another material which appears to decrease intestinal absorption of strontium without a great reduction in calcium absorption is aluminum phosphate gel. Spencer et al. (1967, 1968, 1969) have reported average reductions in strontium uptake of 87.6% in man when 100 to 300 ml of "Phosphaljel" (Wyeth) was consumed immediately prior to ingestion of radiostrontium. Calcium absorption was reduced by 37.8% in this experiment. When administration of 100 ml of Phosphaljel was delayed to $\frac{1}{2}$ or 1 hour after ingestion of the ^{85}Sr absorption was decreased by an average of 57% and 43% respectively. These results were obtained with men on a low calcium diet. A patient fed a high calcium diet showed a depression in ^{85}Sr absorption when aluminum phosphate gel was fed, however another patient receiving a high level of calcium and phosphorus showed no such depression.

This group of investigators also administered 1.5 ml of aluminum phosphate gel to rats immediately prior to, immediately after, 10 minutes after, 30 minutes after and 1 hour after ^{85}Sr consumption and obtained reductions in bone accumulation of ^{85}Sr in amounts of 82, 70, 68, 44, and <0 per cent (Friedland et al. 1968, 1969). Thus the effects of aluminum phosphate gel appear to be very time dependent.

B. Rat Experiments

1. Multi-Supplement Trial

As in the radiocesium study, preliminary experiments with aluminum phosphate gel and sodium alginate were conducted with rats before proceeding to cattle. In order to obtain information on the effectiveness of these products and on possible interactions among dietary conditions a factorial experiment was conducted in which two levels of Ca, P, and Mg were fed to rats with or without sodium alginate and with or without an aluminum phosphate gel. With this design there were eight groups, each containing six rats. The calcium levels fed were 0.95% and 3.0% of the ration. The sodium alginate (Kelco Company's "Kelgin XL"), and the aluminum phosphate gel (Wyeth Laboratories' "Phosphaljel"), were supplemented at rates of 10% of the ration by weight. Calcium-45 and ^{85}Sr were added to the drinking water of the rats. The diets and the radionuclides were fed for one week. Then the rats were killed and femurs ashed and analyzed for ^{45}Ca and ^{85}Sr.

Table 6 summarizes the data obtained from these rats. Table 7 summarizes the results of statistical analysis of these data. Logarithmic transformations were made on the data to reflect proportional changes in strontium and calcium absorption and $OR_{bone/diet}$. The sodium alginate reduced strontium incorporation into bone and the $OR_{bone/diet}$ by significant amounts, whereas the aluminum phosphate gel was much less effective in this experiment. An important observation made was that the effects of most of these supplements appeared to be additive

Table 6. Influence of combinations of dietary supplements on calcium and strontium incorporation into rat femurs

Ca-P-Mg	Alginate	Phosphaljel	^{85}Sr (% of dose)	^{45}Ca (% of dose)	$OR_{bone/diet}$	$OR_{bone/diet}$ per g Ca consumed
Moderate (.95% Ca)	0	0	.225	1.013	.225	.384
		10%	.151	.737	.205	.334
	10%	0	.092	.789	.116	.184
		10%	.083	.755	.111	.178
High (5% Ca)	0	0	.060	.316	.189	.104
		10%	.058	.322	.180	.088
	10%	0	.046	.327	.142	.076
		10%	.043	.315	.135	.071

except for a strong interaction between sodium alginate and the calcium, phosphorus and magnesium content of the ration. The sodium alginate was about twice as effective in lowering the $OR_{bone/diet}$ when the lower level of calcium was fed than when the higher level was fed.

Table 7. Significant effects due to combinations of dietary supplements fed to rats as shown by an analysis of variance of logarithmically transformed data.

Effect	Sr	Ca	Measurement $OR_{femur/diet}$
Ca-P-Mg	**	**	
Alginate	**		**
Phosphaljel	*		
Interactions:			
Ca X Alginate	**		**
Ca X Phosphaljel			
Alginate X Phosphaljel			
Ca X Alginate X Phosphaljel			

* Effect significant at 95% probability level
** Effect significant at 99% probability level

2. Aluminum Phosphate

Further rat experiments were conducted involving the feeding of aluminum phosphate gel and aluminum phosphate (dry chemical). A summary of the results is presented in Table 8. The greatest reduction in radiostrontium incorporation into bones occurred when the aluminum phosphate gel and the radionuclides were administered via stomach tube rather than being mixed with the feed. It should be noted however, that incorporation of radiostrontium in femurs of control rats fed the radioactive material via stomach tube was considerably greater than that observed in control rats fed the radionuclides mixed in their feed. Expressed as percents of consumed dose per femur the respective range of values were .68% to .99% vs. .18% to .22%.

Factors responsible for these effects may include (1) amount of solids vs. liquids in the tract, (2) dehydration of the gel in the feed, and (3) the concentration of the aluminum phosphate gel in the tract when the radiostrontium is being absorbed. Spencer and Friedland indirectly showed the importance of the latter factor when they demonstrated that the relative time of administration of the gel was critical. Although a non-gel form of aluminum phosphate fed in the feed or as a slurry via stomach tube did decrease strontium uptake, the gel form was considerably more effective.

Table 8. Incorporation of ^{85}Sr and ^{45}Ca in femurs of rats fed aluminum phosphates expressed as percentages of control values.

Route[1]	Supplement	^{85}Sr (% of control)	^{45}Ca (% of control)	$OR_{bone/diet}$ (% of control)
via stomach tube	1 ml Phosphaljel[2]	29	87	35
	1 ml Phosphaljel[3]	27	82	33
	2 ml Phosphaljel	13	57	24
	$AlPO_4$ (1 ml equiv.)	51	98	54
via feed	15% Phosphaljel	74	110	67
	20% Phosphaljel	54	106	58
	$AlPO_4$ (20% equiv.)	73	87	79
	$AlPO_4$ (30% equiv.)	60	94	62

[1] Route by which radionuclides and supplements were administered.

[2] Experiment A.

[3] Experiment B.

Sodium Alginate

In the factorial experiment discussed above an alginate derived from Pacific giant kelp was used. A supply of "Manucol-SS/LD/2" was obtained from Alginate Industries, Ltd., London. This is a sodium alginate with a high guluronic acid content and is derived from Laminaria species of brown seaweed. When fed to rats at the rate of 10% of their ration by weight ^{85}Sr incorporation in femurs was reduced by 90% and the $OR_{bone/diet}$ was reduced by 87%. This compares to 59% and 52% respectively when the domestic product was fed.

C. Cattle Experiments

As possible countermeasures against radiostrontium secretion into milk dairy cows in the study reported herein were fed the following materials singly and in combinations: sodium alginate, aluminum phosphate gel, aluminum phosphate, calcium, phosphorous and magnesium.

1. Sodium Alginate Supplementation

Sodium alginate (Manucol SS/LD/2) was fed to four cows. Two cows received this material as the only supplement while the other two received it in combination with other dietary supplements. Cow 167 was fed 2 pounds of sodium alginate per day (7 percent of her feed intake) for three days. On the fourth day the level of sodium alginate fed was reduced to 1.5 pounds or 5 percent of the total feed intake because the cow began to refuse the higher level. The sodium alginate was fed by mixing it with the grain ration. To aid in palatability 5 percent molasses was added to the mixture. Cow 175 would not consume more than 0.8 pounds of sodium alginate per day (3 percent of her ration). For 2½ days this cow received an additional two pounds of sodium alginate per day encased in gelatine capsules and administered by a balling gun.

Radiostrontium (^{85}Sr & ^{89}Sr) and ^{45}Ca were administered as single oral

doses during both the supplementation trials and during control periods. Cow 167 received ^{85}Sr at the initiation of sodium alginate supplementation and ^{89}Sr four days later.

Milk samples were assayed for ^{85}Sr in a large sample scintillation counter. Aliquots of milk were dried, ashed and dissolved in a dilute HCl solution. A liquid scintillation counter was employed to count directly the Cerenkov radiation of the ^{89}Sr in the water-base medium. One ml aliquots of the same solution were placed in Bray's solution and assayed for ^{45}Ca in the liquid scintillation counter. The external standard method (^{133}Ba) was employed for quench corrections.

Data from these experiments are presented in Tables A-6 and A-7. The cumulative radiostrontium secretion and the "accumulated concentration" values have been calculated by methods described in the section of this report dealing with ferric ferrocyanide effects. In addition "cumulative OR" (Σ O.R.) values have been calculated. These are $O.R._{milk/diet}$ values arrived at by dividing the cumulative percent radiostrontium secreted into milk up to a given time by the cumulative percent radiocalcium secreted into milk up to the same time. The $O.R._{milk/diet}$ is thus a measure of the overall discrimination against strontium in favor of calcium between that consumed by the cow and that appearing in the milk.

Comparisons of radiostrontium secretion into milk with and without sodium alginate supplements being fed the cows are shown in Figures 7 and 8 and in Table 9. The peak concentrations of radiostrontium appear to be nearly inversly proportional to the rate of sodium alginate consumption, i.e., Cow 167 received 70% as much sodium alginate as Cow 175 and produced a peak radiostrontium concentration which was 1/0.72 of that of Cow 175. The peak radiostrontium concentration also occurred about one-half day earlier when sodium alginate was fed (1 day vs. 1.7 to 2 days). There was a sharper decline in radiostrontium concentrations in milk when sodium alginate was fed. The rate of decline between the peak concentration and that of day 10 was 1.7 and 2.3 times as fast when the sodium alginate was fed to Cows 175 and 167, respectively, as when no supplement was fed. The 7-day cumulative radiostrontium concentration was reduced by 2/3 in both cows. When ^{89}Sr was fed to Cow 167 four days after the beginning of sodium alginate supplementation (T = 96 hours) the percentage of the isotope appearing in the milk was only slightly less than when the radiostrontium dosing and the initiation of the sodium alginate supplementation occurred at the same time (T = 0). The effect of feeding sodium alginate to Cow 167 on the 7-day cumulative $O.R._{milk/diet}$ was nearly as great as on the radiostrontium concentrations, thus indicating that action of the sodium alginate was primarily on strontium and not on the calcium ingested.

Table 9. Levels of radiostrontium in milk when sodium alginate was fed expressed as percentages of levels observed during the control periods.

Cow	Time[1]	Peak Concentration	7-Day Secretion	7-Day Accumulated Concentration	7-Day Cumulative $O.R._{milk/diet}$
175	0	45.3	20.5	33.1	
167	0	62.0	33.4	34.7	
167	96	57.7	29.7	30.9	37.9

[1] Time in hours between initiation of sodium alginate feeding and administration of radiostrontium.

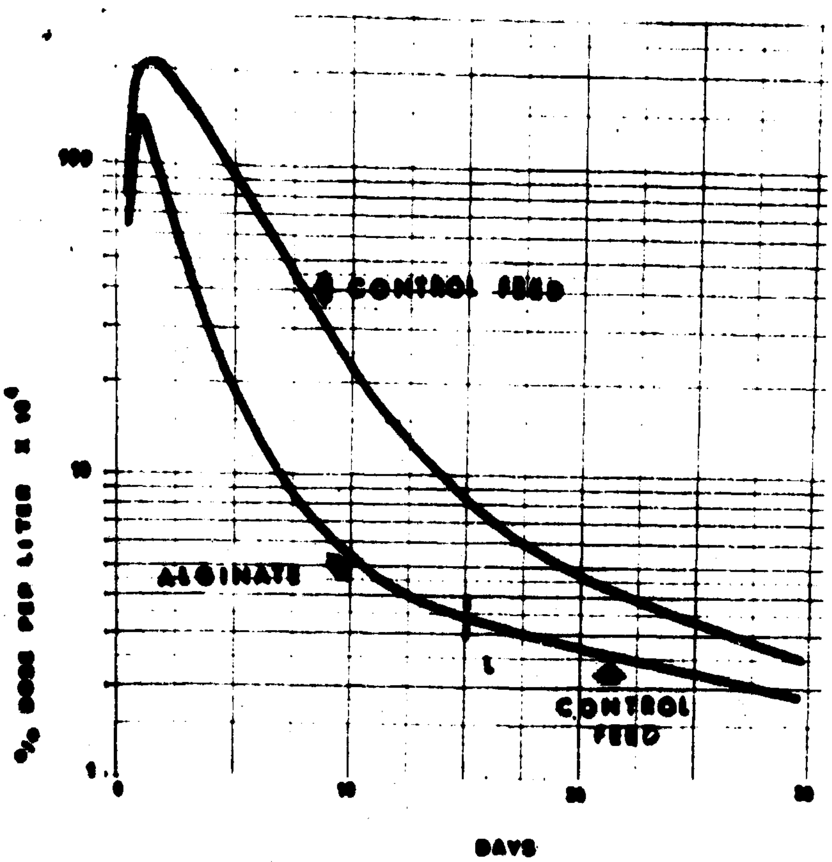

Figure 7. Effect of sodium alginate on concentrations of radio-strontium in the milk of Cow 167 when given a single oral dose of ^{85}Sr.

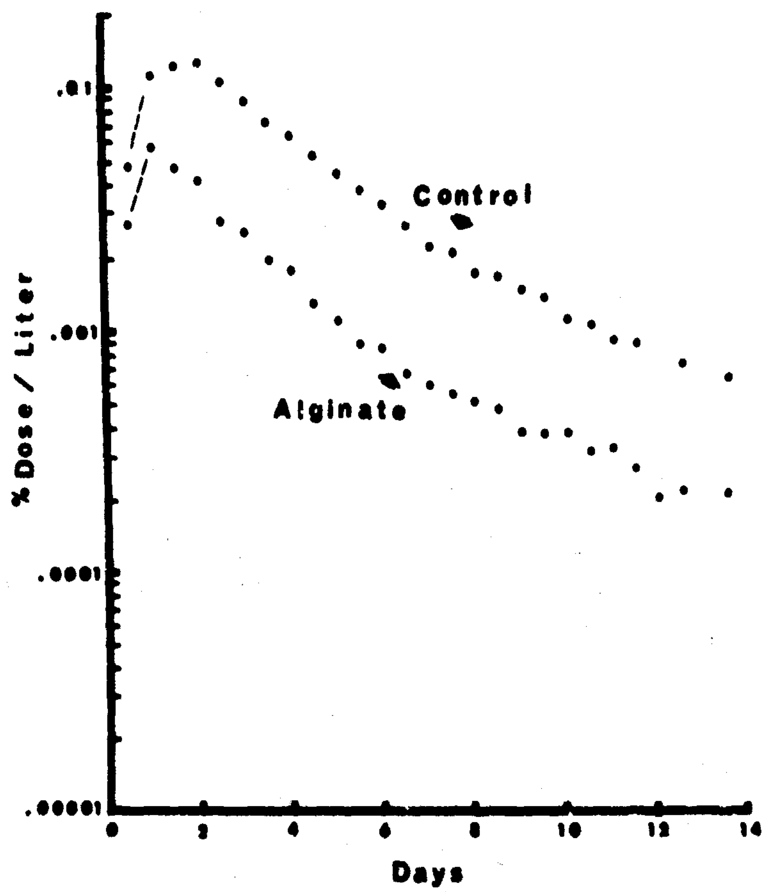

Figure 8. Effect of sodium alginate on concentrations of radio-strontium in the milk of Cow 175 when given a single cral dose of ^{85}Sr.

2. Aluminum Phosphate Gel Supplementation

When a cow was fed aluminum phosphate gel ("Phosphaljel" from Wyeth Laboratories), at a rate of 12 oz. per feeding no appreciable reduction in radiostrontium levels in milk was seen. In order to see if a higher level of supplementation would produce an effect, three cows were fed 3.5 liters of aluminum phosphate gel at the time of ^{85}Sr administration and 1.75 liters at the next feeding. The liquid suspension was administered as a drench.

Levels of ^{85}Sr in milk in these experiments are recorded in Tables A-6, A-7 and A-8. Comparisons with levels in the control periods are presented in Table 10. Considerable variation among animals was observed. On the average the administration of these quantities of aluminum phosphate gel was about one-half as effective in reducing radiostrontium secretion into milk as the sodium alginate supplementation, i.e., reducing the contamination by about one-third in comparison with no supplementation. The shapes of the radiostrontium transfer curves were very similar to those of the respective control period curves.

Table 10. Levels of radiostrontium in milk when aluminum phosphate gel or aluminum phosphate was fed cows expressed as percentages of levels observed during control periods.

Cow	Peak Concentration	7-Day Secretion	7-Day Accumulated Concentration	7-Day Cumulative $O.R._{milk/diet}$
175[1]	93.0	52.8	84.4	97
167[1]	46.4	30.1	41.2	
176[1]	67.4	158.3[3]	67.4	60
178[2]	74.6	78.3	71.3	63

[1] Fed aluminum phosphate gel.

[2] Fed $AlPO_4$ as dry chemical.

[3] Control period was at end of the lactation period of this cow and thus milk secretion was low.

Cow 178 was given aluminum phosphate in the dry chemical form rather than as a gel. Two hundred grams was given at the time of ^{85}Sr dosing and 100 grams at the next feeding which provided nearly equivalent amounts of $AlPO_4$ to that which was administered in the gel form. This cow would not consume her grain ration if the $AlPO_4$ was included at levels of more than 2.5%. The remainder of the supplement was administered in gelatine capsules. Data obtained from this experiment is summarized in Tables A-10 and 10. Although the effect on strontium secretion into milk was not large it is interesting to note that the reduction in the 7-day cumulative radiostrontium concentration was 80 percent of the average reduction observed with the three cows that received the aluminum phosphate in the gel form.

3. Combination of Dietary Supplements

To determine if reductions in radionuclide levels in milk would be additive when more than one dietary supplement was fed, five trials with four cows were initiated. During a control period the cows received a ration with a moderate level of calcium which averaged 82 grams per day. Radioisotopes of Sr, Ca, and Cs were fed as single doses and milk assayed for these nuclides. During the

supplement period the ration which the cows received supplied 309 grams of calcium per day plus supplemental phosphorus and magnesium which were added in amounts of 100 and 25 grams per day respectively. In the first experiment with three cows the maximum level of feeding of Manucol SS/LD/2 which was tolerated by the cows was 3.5% of the ration. In a second experiment with two cows the sodium alginate was pelleted along with some corn meal and lindseed meal. These pellets were fed so as to furnish sodium alginate at a level of 6% of the ration. Ferric ferrocyanide was fed at a rate of 50 grams per day in the first experiment and as a single dose of 50 grams in the second experiment. Because of problems with feed consumption in these trials and due to a limited and variable effect in previous trials, aluminum phosphate gel was not given in these experiments. The cows were fed the rations for 2 to 3 days prior to the administration of the radionuclides.

Two of the cows failed to eat enough of their grain and the supplements contained therein to warrant continuing them on the experiments. The data for the remaining three trials which were conducted are present in Tables A-4B, A-5B, A-5H, A-10 and A-11. In Table 11 the incorporations of radiocesium and radiostrontium into milk when the supplements were fed are expressed as percentages of levels observed during the control period. The responses observed when the cows were fed the combination of supplements was disappointingly poor. While the depression in radiocesium secretion into milk was on the average only slightly less than had been observed in the single supplement experiments, the depression in radiostrontium secretion into milk was considerable less than would have been expected if either sodium alginate alone or an elevation in calcium intake alone had been given. An elevation in dietary calcium alone would be expected to reduce secretion of radiostrontium in milk according to an inverse relationship but would not be expected to greatly alter the $O.R._{milk/diet}$. Undoubtedly a factor contributing to the results observed was the lack of palatability of the grain mixture containing large quantities of salts and sodium alginate. Even though the addition of molasses and the pelleting of the alginate helped, there was definitely more wastage with the supplemented grain mixture. Another factor which may be involved is an interaction between the level of calcium in the ration and the effect of sodium alginate. Such an interaction was observed in a rat experiment described earlier in this report.

Table 11. Levels of radiostrontium and radiocesium in milk when a combination of remedial agents was fed to cows expressed as percentages of levels observed during control periods.

Radio-nuclide	Expt.	Cow	Peak Conc.	7-Day Secretion	7-Day Accumulated Concentration	7-Day Cumulative $O.R._{milk/diet}$
Cs	I	176	7.3	6.1	6.5	
		177	3.5	3.0	3.4	
	II	177	4.8	8.9	7.0	
Sr	I	176	36	39	41	57
		177	82	66	75	94
	II	177	77	72	82	113

V. Prediction of Radionuclide Intake From Milk By Humans

Lengemann (1966, 1968) has described a method for predicting the total intake commitment of a radionuclide from milk for people drinking milk from

cows grazing on a pasture contaminated by a single short-term deposition of fallout. This method has now been expanded to include factors for the deposition rate of the fallout on pasture, situation where cows do not start grazing on the contaminated pasture until some time after the arrival of the fallout and situations where there is more than one deposit separated by an interval of time.

A. General Equation

1. Definitions

I_o^* = amount of biologically absorbable radionuclide which is available for deposition on the area a cow would completely graze per day to supply its nutrient requirements.

t = time of consumption of radioactivity by the cow after first grazing on the contaminated pastures.

T = time of milk secretion after the initial grazing on the contaminated pastures.

D = time between initial deposit and the initial grazing on the contaminated pastures.

β = fallout deposition half-time.

θ = fractional rate of radionuclide deposition ($= .693\ \beta^{-1}$).

λ = fractional rate of radionuclide decay.

ρ = half-time of removal of radionuclide from grass by all processes other than radioactive decay.

v = fractional rate of loss of radionuclide from grass due to all processes but radioactive decay ($= .693\rho^{-1}$).

M = concentration of radionuclide in milk.

$k_1, k_2, k_3 \ldots k_i$ = fractional rate of loss of radionuclide from a biological compartment.

n = number of exponential terms in the general equation.

$a_1, a_2, a_3 \ldots a_i$ = amount of radionuclide in a particular compartment.

2. Derivation

The transfer of ingested iodine, strontium and cesium into milk may be described by empirical equations consisting of the sum of n exponential terms.

The differential contribution of the consumption rate of a radionuclide to the amount of activity appearing in milk at time T can be obtained from such equations which express the transfer of radionuclide into milk after a single dose:

$$(1)\quad dM(T) = I_{(t)} \sum_{i=1}^{n} \left[a_i e^{-(k_i+\lambda)\ (T-t)} \right] dt,$$

where (T-t) is the time between consumption of the isotope by the cow and secretion into milk.

The initial intake rate, $I_{(t)}$ is determined by the amount accumulated less that lost through decay and other modes of removal from grass. For purposes of illustration of the approach a single exponential deposition rate, θ, is assumed. Also note that new definitions for T, t, D and I_o* have been introduced to fit into a more general model. These considerations give rise to an equation for $I_{(t)}$:

$$(2)\quad I_{(t)} = I_o^* \cdot \frac{\theta}{(\lambda+v-\theta)} \cdot \left| e^{-\theta(t+D)} - e^{-(\lambda+v)\ (t+D)} \right|$$

Substituting (2) in equation 1, integrating over the total time of consumption of radioactivity by the cow, and dividing by I_o* gives the fraction of I_o* present in a liter of milk at time T.

$$(3)\quad \frac{M_{(T)}}{I_o^*} = \frac{\theta}{\lambda+v-\theta} \cdot e^{-\lambda T} \cdot \sum_{i=1}^{n} \left[a_i \left(\left(\frac{e^{-(\theta-\lambda)T} - e^{-k_i T}}{k_i+\lambda-\theta} \right) \cdot e^{-\theta D} \right) + a_i \left(\left(\frac{e^{-k_i T} - e^{-vT}}{k_i - v} \right) \cdot e^{-(\lambda+v)D} \right) \right]$$

Equation 3 may be integrated from 0 to infinite time to obtain the total amount of radionuclide that would be ingested by an average member of the human population as a proportion of I_o*. When this total projected intake is divided by the amount of radionuclide ingested on any particular day (from equation 3) a relationship of the intake on this particular day to the total amount that could be ingested over time is established. A factor can be computed for each day after the initial deposition of the radionuclide. In the process of these computations I_o* cancels out and thus the method is independent of the level of contamination on pasture and grazing rates which are usually difficult to measure.

A more detailed discussion of the derivation of F factor was presented in our previous report (TRC-67-33).

In Tables A-12 through A-14 are examples of F values for ^{131}I, ^{137}Cs and ^{90}Sr. These factors have been calculated for various pasture retention times (ρ) and deposition rates (θ). They are based upon equations derived from 6-cow experiments described in our last report (TRC-67-33). F values based upon data for larger numbers of cattle both from this laboratory and obtained from the literature are being prepared (Lengemann, 1966, 1967, 1968).

The effect of a prolonged period for deposition is to delay the time before a peak concentration is observed in the milk. This is reflected in the increase of the value of F for day 1 and the increasing number of days before a minumum F value is achieved.

Similar F values can be calculated for varying delays in placing cows on

the contaminated pasture. As the length of such delays (D) approach or exceed the deposition $t_{1/2}$ (β) the F values calculated rapidly approach F values for an instantaneous deposition of fallout ($\beta = 0$).

To use these F values one multiplies the concentration of a radionuclide in a milk sample taken at a known time after the deposition by the appropriate F and by the average daily consumption (liters) of milk to obtain the total radionuclide intake commitment of an average member of the population from milk due to the contaminating event.

When the half-life of the radionuclide is relatively short (^{131}I) an adjustment must be made in the F values for the intransit delay between milk production and consumption by humans. This may be accomplished by multiplying the F value by $e^{-\lambda \cdot TT}$ where TT is average transit time of milk.

When more than one deposition occurs it is possible to use these F values to predict the combined intake commitment. From a sample of milk after the first event and before the second contaminating event the intake commitment due to the first event (IC_1) can be calculated:

$$(4) \quad IC_1 = F_{1a} \cdot Conc_1 \cdot V$$

where F_{1a} is the F value based upon time between the first deposit and production of the first milk sample which has a radionuclide content of $Conc_1$. V is the volume of milk consumed daily. After the second event the concentration of radionuclide ($Conc_2$) in another milk sample must be determined. The intake commitment (IC_2) due to the second event will be:

$$(5) \quad IC_2 = \left(Conc_2 - \frac{IC_1}{F_{1b}}\right) . F_2 \cdot V$$

where F_{1b} is the F value based upon time between the first deposit and the second milk sample and F_2 is the F value based upon time between the second deposit and the second milk sample.

B. Simulation of Pasture Contamination

In order to experimentally verify that the model described in the preceding section, which is based upon single-dose experiments, would describe the situation where cows graze on contaminated pasture, two experiments were carried out. In each ^{131}I, ^{85}Sr and ^{137}Cs were fed in different amounts each feeding to simulate pasture conditions. A two-incident deposition was assumed with the following conditions:

	Experiment A	Experiment B
Cow No.	178	179
Days between incidents	3	7
ρ (days)	10	14
β - first deposit (hours)	3	12
β^1 - second deposit (hours)	6	24
ρ^2	0	0
I * - first deposit	1	1
I_0^D * - second deposit	$0.5e^{-3\lambda}$	$0.5e^{-3\lambda}$

The dosing schedule was based upon equation 2 and calculated as follows:

$$\text{(6)} \quad \text{Volume of Dose Solution} = Z \cdot \frac{\Theta}{v - \Theta} \left(e^{-\Theta T} - e^{-vT} \right)$$

where Z = 1/(number of times dosed per day). The cows were dosed 3 times per day for three days following each simulated deposit and 2 times per day otherwise. Equation 6 was used to calculate amounts of radionuclides given due to the first deposit. The contribution of the second simulated deposit was calculated using equation 6 except that Z was replaced by 0.5Z, i.e., the second deposit was one half as large as the first.

The data for milk radionuclide levels are presented in Figures 9 through 14. The data for Sr has been adjusted to the half-life of ^{90}Sr rather than ^{85}Sr. The lines are based on equation 3 and were fit to the data by multiplying the calculated concentration by an optimum factor. The latter was calculated from the logarithm of the concentrations to give a least squares fit. The adjustment factors were:

	Experiment A	Experiment B
^{131}I	1.697	.697
^{137}Cs	.773	.742
^{85}Sr	.307	.434

Thus, with the exception of Iodine in one cow, these two cows secreted less ^{131}I, ^{85}Sr, and ^{137}Cs in their milk than the average of 6 cows in the previous study. This is not surprising as considerable variation among cows is to be expected. However, from the standpoint of use of the model according to the method outlined, the level of radionuclide secretion is unimportant whereas the shape of the secretion curve is important.

The calculated concentration curves for ^{90}Sr and ^{137}Cs show a reasonable fit to the data, thus giving assurance that the predictive procedures are valid. In the case of ^{131}I the measured levels in milk of both fell at slightly more rapid rates than the calculated concentrations. During the last portion of the experiments the slope of the theoretical curves are determined to a significant extent only by λ and v. Thus the discrepancy can only be due to a change in efficiency of transfer of ingested ^{131}I into milk by both cows as time progressed or, more probable, due to a loss of ^{131}I in the dosing solution and capsules through volatilization or other processes. The lines plotted in Figures 13 and 14, which fit the data well, were calculated using values for B of 8.5 and 10 days instead of 10 and 14 days respectively. This would indicate that ^{131}I was being lost by processes other than decay at rates of about 57 and 35 days for experiments A and B respectively.

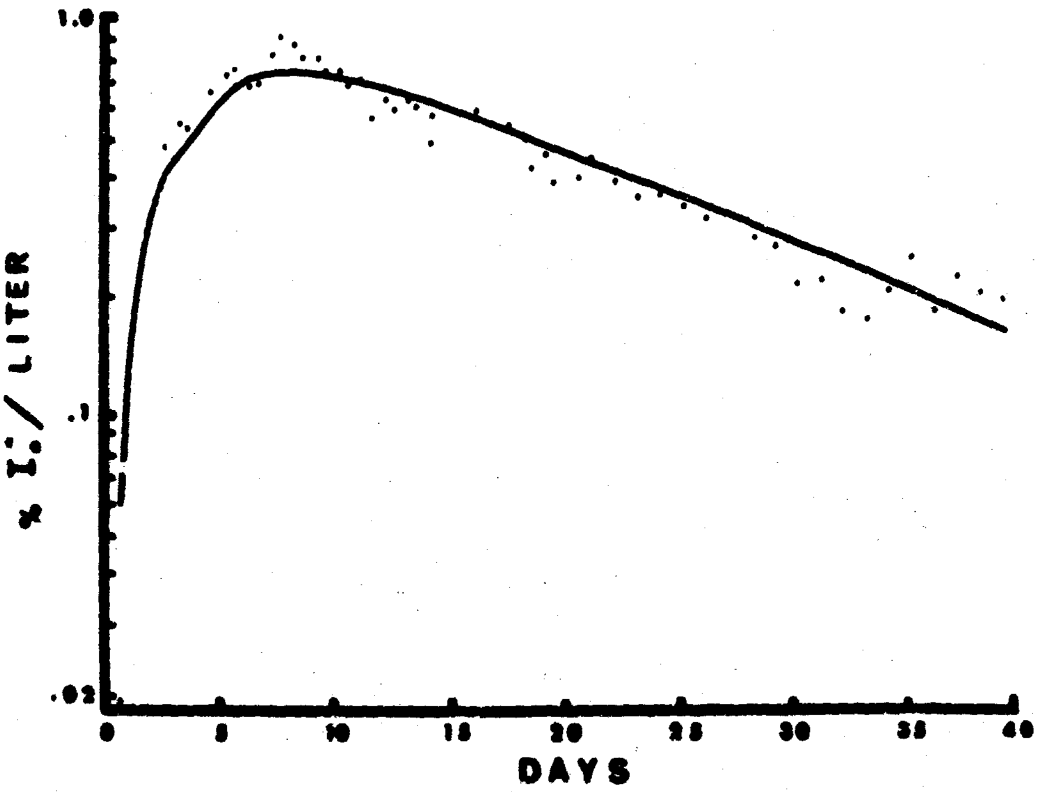

Figure 9. Milk radiocesium concentrations of Cow 178 (Experiment A) when fed ^{137}Cs at rates simulating a grazing situation (points) and the secretion curve computed from the predictive model (line).

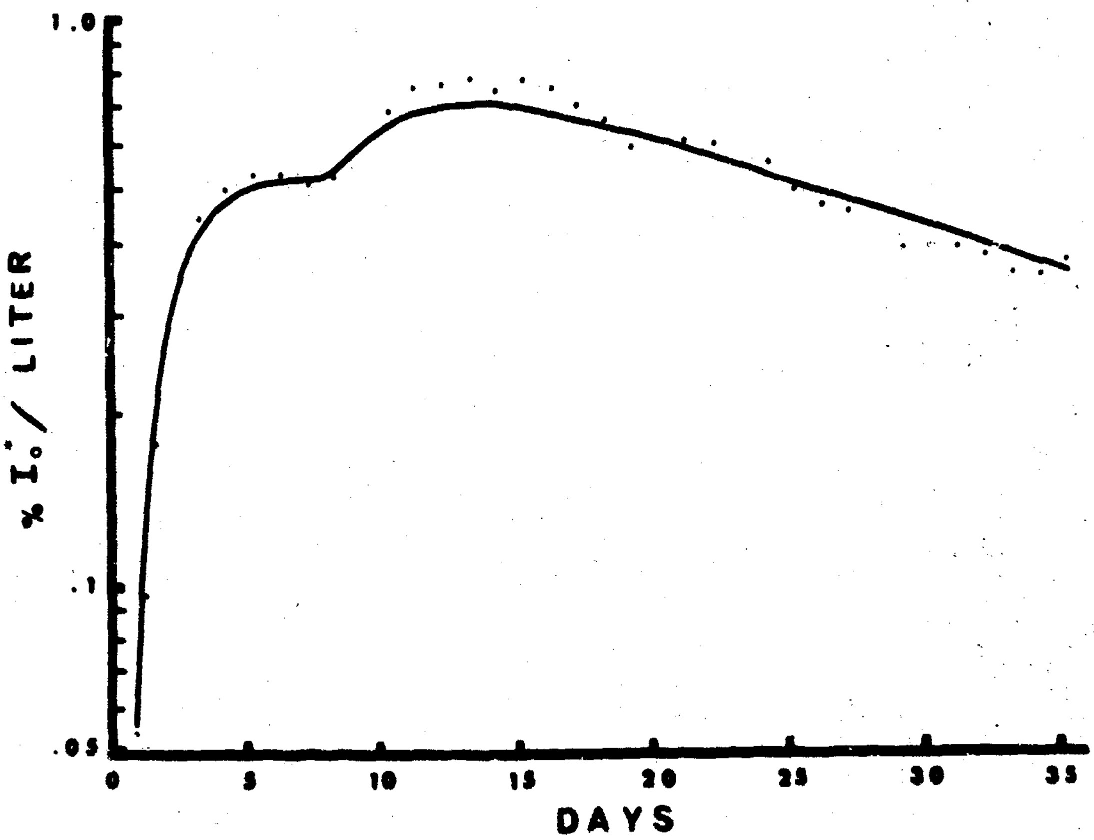

Figure 10. Milk radiocesium concentrations of Cow 175 (ExperimentB) when fed ^{137}Cs at rates simulating a grazing situation (points) and the secretion curve computed from the predictive model (line).

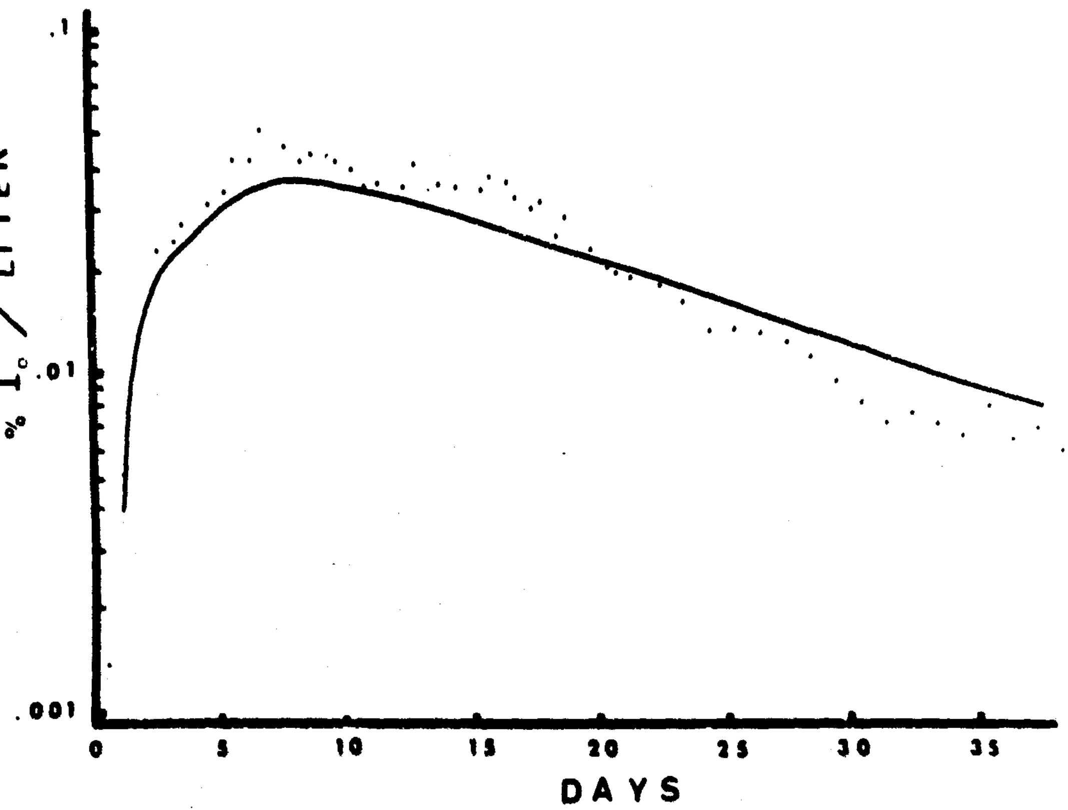

Figure 11. Milk radiostrontium concentrations of Cow 178 (Experiment A) when fed ^{89}Sr at rates simulating a grazing situation (points) and the secretion curve computed from the predictive model (line).

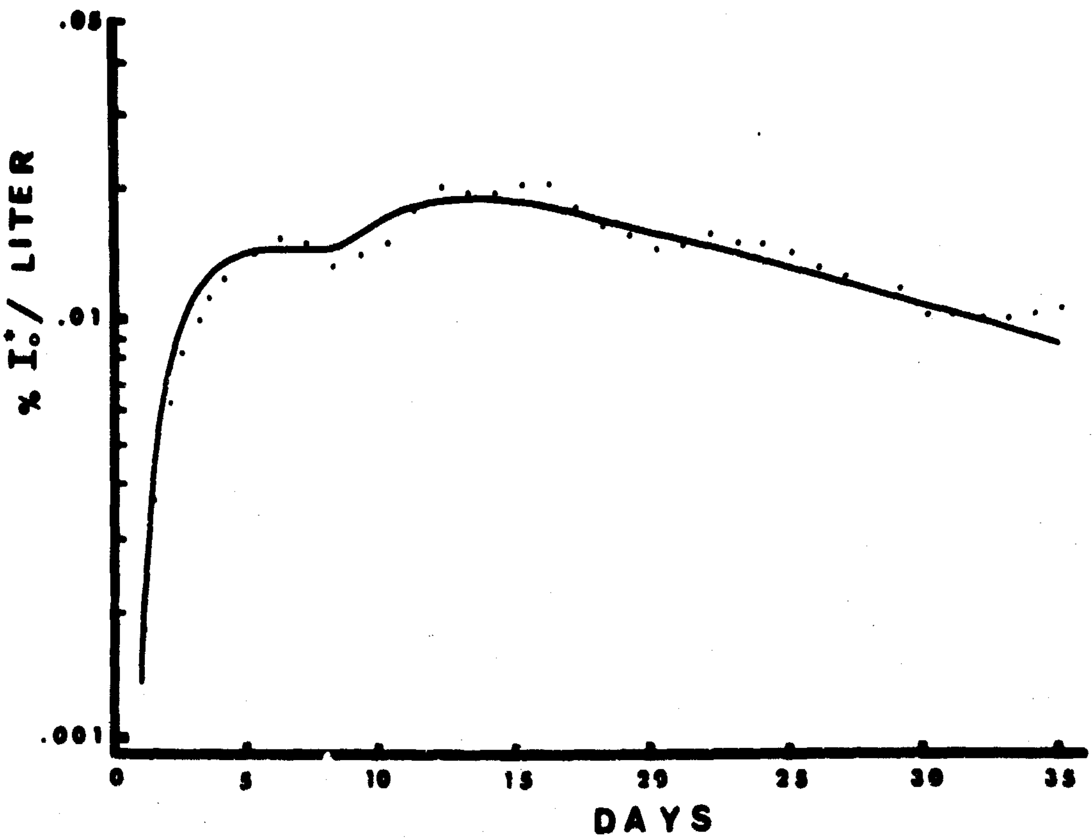

Figure 12. Milk radiostrontium concentrations of Cow 175 (Experiment B) when fed ^{85}Sr at rates simulating a grazing situation (points) and the secretion curve computed from the predictive model (line).

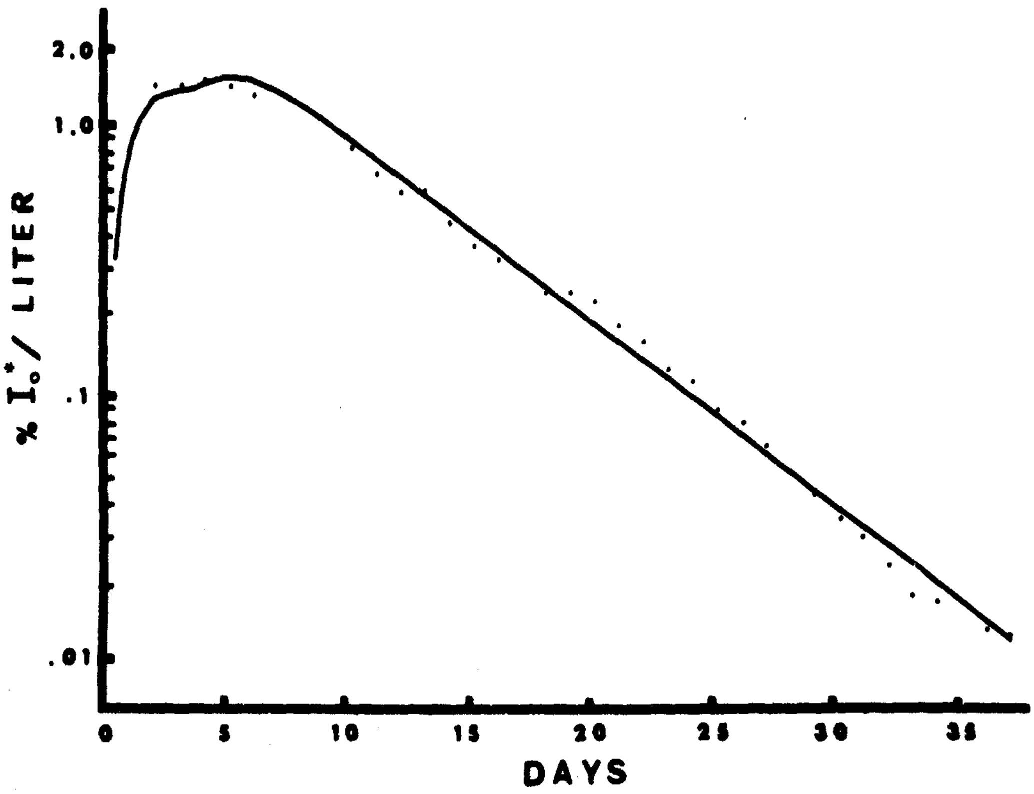

Figure 13. Milk radioiodine concentrations of Cow 178 (Experiment A) when fed ^{131}I at rates simulating a grazing condition (points) and the secretion curve computed from the predictive model using v = 8.5 days (line).

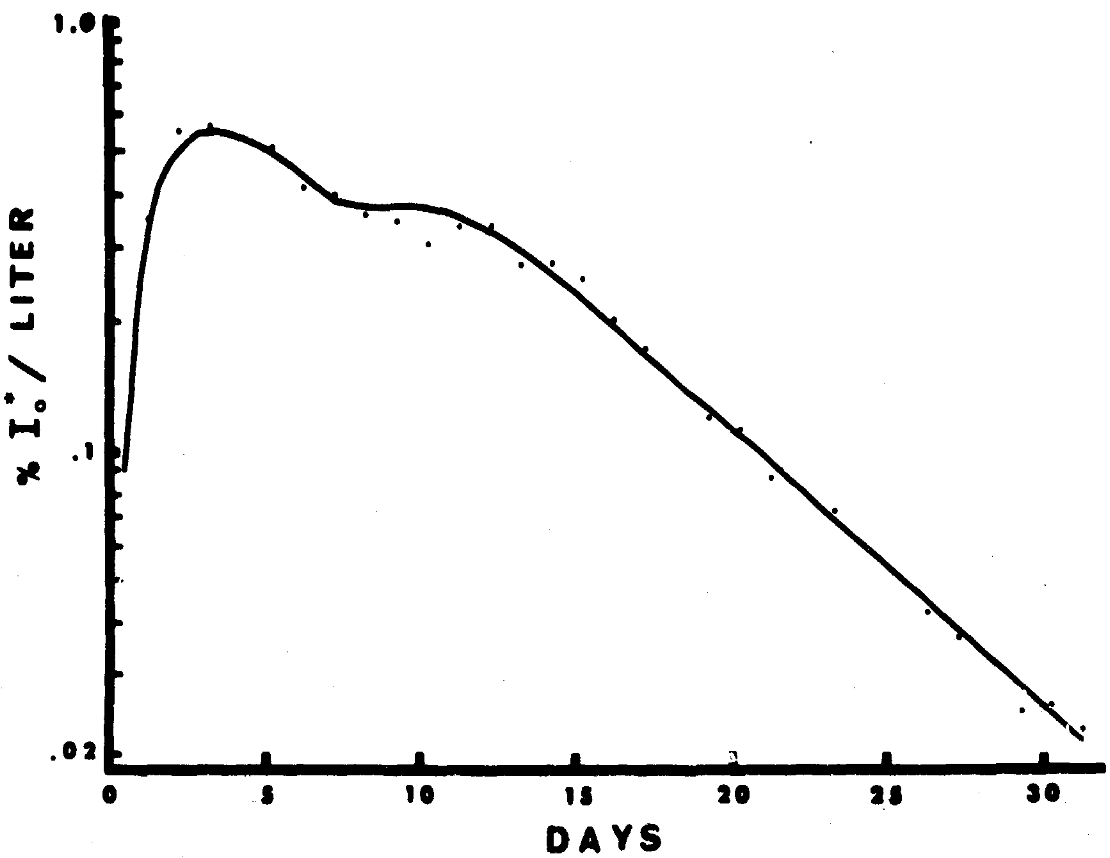

Figure 14. Milk radioiodine concentrations of Cow 175 (Experiment B) when fed ^{131}I at rates simulating a grazing condition (points) and the secretion curve computed from the predictive model using v = 10 days (line).

VI Summary

Following a nuclear event which contaminates the environment with radioactive fallout the major source of ingested ^{131}I, ^{90}Sr, and ^{137}Cs for large segments of the human population is via milk. In dealing with the problems which would arise as a result of such an event two factors must be considered. First, a reliable estimate of the total intake commitment of the radionuclides by an average member of the population should be obtainable. Secondly, if the projected commitments are adjudged greater than acceptable, it is important to have available a selection of countermeasures, each of which would reduce the amounts ingested by humans by a predictable quantity.

A method for the prediction of the total intake commitment of ^{137}Cs, ^{131}I and ^{90}Sr from milk by average members of a human population following deposition of fallout on pasture has been broadened to be made applicable to more situations. The method will account for either a rapid or extended depositions, one or more nuclear incidents separated in time and situations where cattle are on pasture at the time of deposition or turned out to pasture at some time later. The important advantage of the procedure is that predictions do not depend on values of surface contamination of pasture which are difficult to obtain and interpret.

Cows have been fed ^{131}I, ^{85}Sr and ^{137}Cs at rates simulating changing pasture contamination levels after a two-stage nuclear incident. The concentrations of radionuclides measured in milk followed the patterns predicted from the mathematical model thus supporting the basis upon which the predictive method is founded.

Sodium alginate derived from Laminaria species when fed rats and cattle was more effective as a countermeasure against radiostrontium than previously used sodium alginates. When fed to lactating cows at rates of 5 to 7 percent of their ration radiostrontium levels in milk were reduced to 1/3 of control levels without greatly altering calcium metabolism. An indication of a possible interaction between the level of calcium consumed and the effectiveness of sodium alginate was noted in the rat and cattle experiments. Although sodium alginate was shown to be effective as a countermeasure against ^{90}Sr, problems in palatability and economics would probably deter its use until they are overcome.

Reductions in radiostrontium levels in milk when aluminum phosphate gel was fed were quite variable among cows. In three cows the average level of radiostrontium in milk when 3.5 liters of the gel was fed was 64% of control levels. Aluminum phosphate as a dry chemical may be as effective as the gel in the cow but further studies are needed to confirm this observation.

Ferric ferrocyanide (Prussian Blue) was shown to be very effective in reducing ^{137}Cs levels in milk. When 50 grams of ferric ferrocyanide was fed per day radiocesium levels in milk were only 1 to 5% of levels observed in a control period. Ferric ferrocyanide both decreases absorption of radiocesium and increases turnover of retained radiocesium, even several months after the ingestion of the radionuclide. It is believed that this chemical has potentialities as a dietary countermeasure against ^{137}Cs.

VII. References

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VIII. Appendix Tables

Table A-1 Symbols Used in Appendix Tables

Symbol		Definition
%/L	-	percent dose per liter milk
Σ%	-	accumulated secretion into milk
E%/(L/Day)	-	accumulated concentration
*	-	morning milk samples only from date indicated and thereafter
Σ O.R.	-	accumulated O.R.$_{milk/diet}$
T.	-	time between start of supplementation and radionuclide dosing
P.B.	-	ferric ferrocyanide (Prussian Blue)

Table A-2 Radiocesium Secretion Into Milk by Cow 174[1]

A - Control

Day	%/L	Σ%	Σ%/(L/Day)
.67	.3709		
1.00	.6991	2.82	
1.67	.6564		
2.00	.5237	6.69	
2.67	.3985		
3.00	.3242	9.00	
4.00	.2536*	10.47	
5.00	.1754	11.46	1.88
6.00	.1325	12.25	2.00
7.00	.0995	12.93	2.07
8.00	.0831	13.43	2.15
9.00	.0667	13.84	2.21
10.00	.0562	14.21	2.26
11.00	.0500	14.50	2.32
12.00	.0437	14.76	2.38
13.00	.0401	15.00	2.42
14.00	.0357	15.22	2.46
15.00	.0328	15.42	2.49
16.00	.0293	15.60	2.52
17.00	.0277	15.77	2.55
18.00	.0258	15.91	2.59
19.00	.0234	16.05	2.62

(Control)

Day	%/L	Σ%	Σ%/(L/Day)
20	.0220	16.17	2.65
25	.0169	16.71	2.78
30	.0131	17.13	2.86
35	.0116	17.49	2.92
40	.0090	17.75	3.01
45	.0072	17.97	3.07
50	.0066	18.15	3.12
55	.0056	18.30	3.18
60	.0047	18.43	3.23
65	.0042	18.54	3.29
70	.0033	18.62	3.34
75	.0031	18.70	3.40
80	.0028	18.77	3.44

B - Single Dose
50g. P.B, T=0.

Day	%/L	Σ%	Σ%/(L/Day)
.67	.00492		
1.00	.0101	.031	
1.67	.01162		
2.00	.01192	.086	
2.67	.0110		
3.00	.00955	.135	
4.00	.00812*	.167	
5.00		.186	.0431
6.00	.00515	.212	.0478
7.00	.00410	.229	.0521
8.00	.00407	.247	.0560
9.00	.00308	.262	.0589
10.00	.00303	.276	.0619
11.00	225	.286	.0641
12.00	198	.295	.0660
13.00	189	.304	.0676
14.00	158	.311	.0690
15.00	150	.319	.0703

1 See Table A1 for key to symbols

Table A-2 (Continued)

	C - Daily Feeding 50g. P.B/day, T=0			D - Daily Feeding 25g. P.B/day, T=C			E - Daily Feeding 10g. P.B/day, T=0		
Day	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)
.67	.01368			.02075			.0480		
1.00	.02681	.0834		.04199	.145		.0773	.236	
1.67	.02119			.03135			.0664		
2.00	.01500	.171		.02257	.282		.0472	.477	
2.67	.00966			.01451			.0312		
3.00	.00733	.209		.01132	.342		.0249	.624	
4.00	.00507*	.232		.00796*	.374		.0179*	.699	
5.00	.00300	.245	.0537	.00528	.395	.0864	.0112	.745	.169
6.00	.00177	.252	.0556	.00342	.409	.0913	.0077	.779	.176
7.00	.00147	.258	.0572	.00200	.419	.0923	.0054	.803	.182
8.00	.00111	.263	.0586	.00220	.426	.0939	.0047	.822	.188
9.00	.00097	.266	.0597	.00182	.434	.0955	.0036	.838	.190
10.00	.00066	.269	.0608	.00142	.440	.0971	.0037	.854	.194
11.00	.00059	.272	.0612	(.00137)			(.0024)		
12.00	.00050	.274	.0618	(.00140)			(.0033)		
13.00	.00046	.276	.0620	(.00152)			(.0028)		
14.00	.00043	.278	.0621	(.00154)			(.0030)		
15.00							(.0025)		
16.00	(.00048)						(.0027)		
17.00	(.00038)						(.0032)		
18.00	(.00047)						(.0027)		
19.00	(.00042)						(.0021)		

Table A-2 (Continued)

	F - Daily Feeding 50g. P.B/day, T=+48			G - Daily Feeding 25g. P.B/day, T=+48			H - Daily Feeding 10g. P.B/day, T=+48		
Day	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)
.67	.00302			.00904			.0130		
1.00	.00957	.0229		.01976	.053		.05195	.138	
1.67	.00905			.01684			.04425		
2.00	.00691	.0595		.01313	.116		.03697	.326	
2.67	.00491			.00945			.02541		
3.00	.00367	.0789		.00679	.151		.02064	.430	
4.00	.00262*	.0898		.00492*	.169		.01371*	.487	
5.00	.00188	.0977	.0216	.00273	.181	.0415	.00847	.511	.112
6.00	.00145	.1036	.0232	.00180	.186	.0424	.00533	.533	.118
7.00	.00120	.1090	.0244	.00122	.191	.0432	.00380	.537	.120
8.00				.00096	.195	.0441	.0029	.540	.121
9.00				(.00073)			(.0028)		
10.00				(.00061)			(.0028)		
11.00				(.00057)			(.0024)		
12.00				(.00052)			(.0023)		
13.00							(.0022)		
14.00							(.0021)		
15.00							(.0020)		
16.00							(.0017)		
17.00							(.0017)		
18.00							(.0014)		
19.00							(.0014)		

Table A-3 Radiocesium Secretion Into Milk by Cow 175[1]

	A - Control			B - Daily Feeding 50g. P.B/day, T=0			C - Daily Feeding 50g. P.B/day, T=+48		
Day	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)
.67	.139			.008			.00393		
1.00	.265	1.248		.0142	.065		.00911	.036	
1.67	.211			.0123			.00900		
2.00	.188	2.64		.01025	.139		.00672	.089	
2.67	.121			.00631			.00403		
3.00	.107	3.31		.00479	.178			.115	
4.00	.079*	3.83		.00326*	.197		.00215*	.131	
5.00	.051	4.14	.642	.00197	.210	.0326	.00133	.140	.0207
6.00	.041	4.42	.680	.00124	.219	.0333	.00107	.146	.0215
7.00	.032	4.62	.713	.00088	.225	.0339	.00072	.153	.0221
8.00	.024	4.77	.739	.00065	.232		(.00060)		
9.00	.022	4.92	.760	.00056	.234	.0334	(.00067)		
10.00	.018	5.05	.773	(.00055)			(.00042)		
11.00				(.00055)			(.00041)		
12.00				(.00060)			(.00041)		
13.00				(.00050)			(.00035)		
14.00				(.00053)					
15.00				(.00048)					

1 See Table A1 for key to symbols

Table A-4 Radiocesium Secretion into Milk of Cow 176 [1]

	A - Control			B - Daily Dose 50g PB/day, T=+24		
Day	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)
.67	.1344			.00804		
1.00	.238	1.79		.01728	.111	
1.67	.152			.01138		
2.00	.0978	3.21		.00837	.209	
2.67	.0794			.00544		
3.00	.0693	4.11		.00409	.263	
4.00	.0524*	4.69		.00303*	.296	
5.00	.0344	5.06	.460	.00193	.317	.0310
6.00	.0258	5.35	.483	.00114	.328	.0322
7.00	.0195	5.57	.501	.00114	.342	.0327
8.00	.0177	5.74	.525	.00067	.350	.0331
9.00	.0131	5.88	.541	.00062	.357	.0336
10.00	.0109	6.01	.549	.00033	.361	.0335
11.00	.0091	6.10	.559			
12.00	.0079	6.19	.568			
13.00	.0091	6.29	.577			
14.00	.0062	6.35	.584			
15.00	.0050	6.41	.585			

1 See Table A1 for key to symbols

Table A-5 Radiocesium Secretion Into Milk by Cow 177[1]

	A - Control (1-27-69)			B - Daily Feeding 50g/day, T=+24		
Day	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)
.67	.1056			.00260		
1.00	.1840	1.39		.00608	.0317	
1.67	.1685			.00645		
2.00	.1265	2.96		.00488	.0834	
2.67	.0950			.00317		
3.00	.0731	3.88		.00262	.111	
4.00	.0574*	4.43		.00162*	.126	
5.00	.0422	4.83	.472	.00229	.146	.0165
6.00	.0316	5.14	.502	.00093	.155	.0174
7.00	.0250	5.38	.526	.00078	.162	.0181
8.00	.0179	5.57	.541	.00047	.166	.0186
9.00	.0149	5.74	.552	.00048	.171	.0191
10.00	.0128	5.87	.564	.00040	.175	.0193
11.00	.0107	5.99	.573			
12.00	.0096	6.08	.585			
13.00	.0058	6.14	.592			
14.00	.0083	6.22	.600			
15.00	.0088	6.32	.608			
16.00	.0074	6.40	.616			
17.00	.0075	6.47	.624			

1 See Table A1 for key to symbols

Table A-5 (Continued)

	C - Control (6-26-69)			D - Daily Feeding 50g. P.B/day, T=0 (6-12-69)			E - Daily Feeding 50g. P.B/day, T=+48 (6-12-69)		
Day	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)
.67	.118			.0077			.00577		
1.00	.221	1.25		.0144	.070		.00931	.050	
1.67	.166			.0105			.00754		
2.00	.138	2.46		.00790	.121		.00577	.102	
2.67	.095			.00536			.00395		
3.00	.088	3.21		.00438	.157			.133	
4.00	.061*	3.59		.00308*	.180		.00193*	.149	
5.00	.046	3.89	.534	.00182	.194	.0274	.00138	.161	.0204
6.00	.036	4.11	.580	.00144	.206	.0283	.00091	.169	.0211
7.00	.026	4.27	.614	.00093	.214	.0287	.00064	.174	.0219
8.00	.018	4.37	.643	.00075	.220	.0291	(.00056)		
9.00	.018	4.47	.672	.00068	.226	.0297	(.00037)		
10.00	.015	4.58	.689	(.00055)			(.00043)		
11.00				(.00061)			(.00050)		
12.00				(.00056)			(.00027)		
13.00				(.00064)					
14.00				(.00055)					

Table A-5 (Continued)

Day	F - Daily Feeding 50g. P.B/day, T=-24 (7-9-69) %/L	Σ%	Σ%/(L/Day)	G - Daily Feeding 50g. P.B/day, T=-8 (7-9-69) %/L	Σ%	Σ%/(L/Day)	H - Single Dose 50g. P.B, T=0 (4-24-69) %/L	Σ%	Σ%/(L/Day)
.33				.029					
.67	.1309						.00406		
1.00	.1962	1.05		.0949	.477		.00924	.047	
1.33				.0610					
1.67	.0984						.01071		
2.00	.0770	1.65		.0303	.751		.01048	.137	
2.33				.0218					
2.67	.0387						.00904		
3.00	.0344	1.92		.0222	.926		.00833	.214	
3.33				.0168					
3.67	.0288						.00662		
4.00	.0271	2.12		.0127	1.033			.278	
4.33				.0120					
4.67	.0214						.00518		
5.00	.0202	2.27	.328	.0105	1.107	.158		.326	.0368
6.00	.0160	2.38	.340	.0069	1.164	.164	.00350*	.358	.0403
7.00	.0137	2.48	.355	.0059	1.207	.169	.00254*	.380	.0428
8.00							.00219*	.400	.0450
9.00							.00181*	.416	.0469
10.00							.00140*	.428	.0482
11.00							.00136*	.440	.0496
12.00							.00114*	.451	.0506
13.00							.00106*	.460	.0517
14.00							.00092*	.468	.0528

* AM Samples: Subtract 1/3 Day

Table A-6 Effect of Aluminum Phosphate Gel and Sodium Alginate on the Secretion of Radiostrontium in Milk of Cow 167[1]

	A - Control				B - 3.7 l. Phosphaljel at T=0, 1.8 l. Phosphaljel at T=+16		
Day	%/L	Σ%	Σ%/(L/Day)	ΣO.R.	%/L	Σ%	Σ%/(L/Day)
.67	.00782				.00445		
1.00	.0204	.0695		.101	.00986	.026	
1.67	.0213				.00989		
2.00	.0197	.192		.096	.00903	.067	
2.67	.0177				.00776		
3.00	.0176	.297		.096	.00657	.097	
4.00	.0139*	.373		.098	.00566*	.120	
5.00	.0105	.432	.075	.100	.00389	.135	.0324
6.00	.00816	.479	.083	.101	.00266	.146	.0349
7.00	.00589	.512	.089	.103	.00186	.154	.0367
8.00	.00487	.538	.094	.104	.00146	.160	.0376
9.00	.00353	.559	.097	.106	.00106	.165	.0388
10.00	.00248	.573	.099		.00076	.168	.0397
11.00	.00186	.583	.101		.00064	.170	.0404
12.00	.00147	.592	.102		.00059	.173	.0411
13.00	.00130	.600	.103		.00048	.175	.0415
14.00	.00112	.606	.104		.00046	.176	.0424
15.00	.00087	.612	.105		.00037	.178	.0424

1 See Table A1 for key to symbols

Table A-6 (Continued)

	C - Sodium Alginate T=0			D - Sodium Alginate T=+96			
Day	%/L	Σ%	Σ%/(L/Day)	%/L	Σ%	Σ%/(L/Day)	ΣO.R.
.67	.00622			.00048			
1.00	.0134	.0477		.0123	.020		.044
1.67	.00988			.0106			
2.00	.00834	.0973		.00921	.075		.042
2.67	.00625			.00668			
3.00	.00444	.129		.00526	.109		.041
4.00	.00341*	.147		.00332*	.127		.040
5.00	.00163	.157	.0283	.00212	.139	.0248	.040
6.00	.00156	.165	.0299	.00139	.147	.0263	.039
7.00	.00108	.171	.0309	.00100	.152	.0275	.039
8.00	.00078	.175	.0315	.00085	.160	.0294	.040
9.00	.00071	.179	.0322	.00060	.163	.0300	.040
10.00	.00067	.183	.0330	.00066	.167	.0307	.040
11.00	.00062	.187	.0338				
12.00	.00039	.188	.0344	.00044	.172	.0319	.040
13.00	.00037	.191	.0349				
14.00	.00039	.193	.0353				
15.00	.00043	.195	.0360				

Table A-7 Effect of Aluminum Phosphate Gel and Sodium Alginate on the Secretion of Radiostrontium in the Milk of Cow 175[1]

	A - Control				B - 3.7 l. Phospahljel at T=0, 1.8 l. Phosphaljel at T=+16				C - Sodium Alginate T=0		
Day	%/L	Σ%	Σ%/(L/Day)	ΣO.R.	%/L	Σ%	Σ%/(L/Day)	ΣO.R.	%/L	Σ%	Σ%/(L/Day
.67	.00489				.00556				.00283		
1.00	.01188	.083		.082	.0116	.0517		.084	.00585	.028	
1.67	.01248				.0120				.00494		
2.00	.01290	.227		.077	.0110	.135		.077	.00423	.061	
2.67	.01085				.00930				.00288		
3.00	.00899	.345		.075	.00816	.200		.073	.00260	.079	
4.00	.00747*	.420		.073	.00597*	.237		.071	.00203*	.092	
5.00	.00551	.478	.0425	.072	.00373	.262	.0371	.069	.00133	.101	.0146
6.00	.00391	.518	.0463	.071	.00254	.276	.0392	.068	.00091	.108	.0154
7.00	.00276	.547	.0489	.070	.00196	.289	.0413		.00069	.112	.0162
8.00	.00218	.571	.0507	.070	.00157	.301	.0427		.00057	.116	.0169
9.00	.00173	.590	.0525	.070	.00112	.309	.0437		.00048	.119	.0173
10.00	.00145	.605	.0539	.070	.00097	.316	.0445		.00039	.121	.0177
11.00	.00111	.616	.0552	.071					.00033	.124	.0180
12.00	.00092	.625	.0564	.071					.00028	.125	.0182
13.00	.00077	.634	.0572	.070					.00023	.127	.0185
14.00	.00066	.641	.0578	.070					.00022	.128	.0188

1 See Table A1 for key to symbols

Table A-8 Effect of Aluminum Phosphate Gel on the Secretion of Radiostrontium in the Milk of Cow 176[1]

Day	A - Control				B - 3.7 l. Phosphalgel at T=0, 1.8 l. Phosphalgel at T=+16			
	%/L	Σ%[2]	Σ%/(L/Day)	ΣO.R.	%/L	Σ%[2]	Σ%/(L/Day)	ΣO.R.
.67	.0076				.00455			
1.00	.0147	.035		.169	.00814	.0405		.0743
1.67	.0176				.01173			
2.00	.0165	.096		.138	.01186	.106		.0753
2.67	.0114				.01069			
3.00	.0095	.127		.132	.00995	.181		.0773
4.00	.0069*	.149		.122	.00572*	.220		.0733
5.00	.0042	.162	.0494	.117	.00340	.245	.0351	.0705
6.00	.0029	.170	.0530		.00240	.265	.0367	.0694
7.00	.0018	.175	.0556		.00135	.277	.0375	.0682
8.00	.0015	.180	.0571		.00085	.284	.0377	
9.00	.0011	.184	.0570		.00058	.288	.0382	
10.00	.0006	.186	.0564		.00052	.293	.0383	
11.00					.00040	.296	.0382	
12.00					.00035	.299	.0382	
13.00					.00028	.302	.0384	
14.00					.00025	.304	.0385	

1 See Table A1 for key to symbols

2 See text for discussion of total amounts of radiostrontium secreted in this experiment.

Table A-9 Effect of $AlPO_4$ on the Secretion of Radiostrontium in the Milk of Cow 178[1]

Day	A - Control %/L	A - Control Σ%²	A - Control Σ%/(L/Day)	A - Control ΣO.R.	B - 200g $AlPO_4$ at T=0, 80g $AlPO_4$ at T=+16 %/L	B Σ%²	B Σ%/(L/Day)	B ΣO.R.
.67	.0031				.00262			
1.00	.0070	.0380		.094	.00621	.037		.0536
1.67	.0080				.00642			
2.00	.0086	.109		.087	.00613	.094		.0515
2.67	.0069				.00498			
3.00	.0066	.167		.085	.00450	.138		.0522
4.00	.0049*	.210		.085	.00353*	.167		.0530
5.00	.0033	.238	.0280	.085	.00227	.189	.0204	.0535
6.00	.0021	.255	.0301		.00140	.202	.0218	.0533
7.00	.0015	.268	.0317		.00086	.210	.0226	.0533
8.00	.0012	.278	.0329		.00059	.216	.0231	
9.00	.0009	.285	.0338		.00044	.220	.0235	
10.00	.0006	.290	.0343		.00035	.223	.0237	
11.00	.0005	.295	.0349		.00028	.226	.0239	
12.00					.00021	.228	.0241	
13.00					.00018	.229	.0243	
14.00					.00015	.231	.0245	

1 See Table A1 for key to symbols.

Table A-10 Effect of Combinations of Ca, P, Mg and Sodium Alginate Supplements on Radiostrontium Secretion in Milk of Cow 176[1]

	A - Control				B - Supplementation			
Day	%/L	Σ%	Σ%/(L/Day)	ΣO.R.	%/L	Σ%	Σ%/(L/Day)	ΣO.R.
.67	.00931				.00328			
1.00	.0215	.142		.098	.00656	.043		.052
1.67	.0206				.00759			
2.00	.0177	.346		.087	.00784	.116		.051
2.67	.0147				.00635			
3.00	.0121	.511		.093	.00615	.184		.053
4.00	.0083	.599			.00422	.229		.055
5.00	.0048	.648	.0590		.00230	.254	.0249	.056
6.00	.0031	.682	.0616		.00124	.267	.0261	.056
7.00	.0020	.704	.0633		.00077	.276	.0263	
8.00	.0012	.715	.0654		.00052	.282	.0267	
9.00	.0008	.724	.0665		.00041	.286	.0270	
10.00	.00058	.730	.0668		.00036	.290	.0270	
11.00	.00050	.736	.0673					
12.00	.00042	.740	.0679					
13.00	.00042	.744	.0684					
14.00	.00032	.748	.0687					
15.00	.00033	.752	.0685					

1 See Table A1 for key to symbols

Table A-11 Effect of Combinations of Ca, P, Mg and Sodium Alginate Supplement on Radiostrontium Secretion in Milk of Cow 177[1]

	A - Control (I)				B - Supplementation (I)			
Day	%/L	Σ%	Σ%/(L/Day)	ΣO.R.	%/L	Σ%	Σ %/(L/Day)	ΣO.R.
.67	.00593				.00412			
1.00	.0124	.087		.089	.01079	.053		.109
1.67	.0131				.01053			
2.00	.0122	.218		.084	.00860	.140		.102
2.67	.00904				.00658			
3.00	.00750	.308		.093	.00510	.196		.100
4.00	.00562*	.361		.108	.00453*	.237		.102
5.00	.00299	.390	.0382		.00229	.258	.0291	.102
6.00	.00213	.411	.0401		.00156	.272	.0307	.102
7.00	.00140	.426	.0417		.00096	.281	.0314	
8.00	.00101	.437	.0425		.00066	.288	.0322	
9.00	.00074	.445	.0429		.00049	.291	.0325	
10.00	.00060	.452	.0434		.00039	.295	.0325	
11.00	.00051	.457	.0438					
12.00	.00050	.462	.0445					
13.00	.00034	.466	.0449					
14.00	.00040	.470	.0453					
15.00	.00034	.473	.0455					

1 See Table A1 for key to symbols

Table A-11 (Continued)

Day	C - Control (II) %/L	C - Control (II) Σ%	C - Control (II) Σ%/(L/Day)	C - Control (II) ΣO.R.	D - Supplementation (II) %/L	D - Supplementation (II) Σ%	D - Supplementation (II) Σ%/(L/Day)	D - Supplementation (II) ΣO.R.
.67	.00386				.00318			
1.00	.0101	.0618		.0895	.00855	.0405		.097
1.67	.01144				.00878			
2.00	.01080	.171		.0822	.00785	.112		.092
2.67	.00897				.00535			
3.00		.266		.0804	.00424	.156		.091
4.00	.00550*	.318		.0798	.00310*	.185		.090
5.00	.00325	.350	.0353	.0796	.00212	.206	.0232	.090
6.00	.00221	.371	.0378		.00111	.215	.0243	
7.00	.00153	.389	.0385		(.00728)	.280	.0316	
8.00	.00112	.400	.0398		(.00585)	.332	.0374	
9.00					(.00373)	.365	.0412	
10.00					(.00310)	.393	.0442	
11.00					(.00261)	.416	.0469	
12.00					(.00211)	.435	.0489	
13.00					(.00185)	.452	.0507	

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Table A-12. $F_{^{131}I}$ values for days between initiation of grazing of contaminated pasture and production of a given milk sample.

Days on Pasture	Halftime of Fallout Deposition in Days (p) 0	.125	.25	.5	1	2	4
ρ = 7 days							
1.	13.2	15.8	19.6	28.6	47.5	65.8	102.[illegible]
2.	9.2	9.5	10.1	12.0	16.8	27.3	48.7
3.	8.9	8.8	8.9	9.5	11.[illegible]	17.0	28.4
4.	9.6	9.4	9.3	9.3	10.3	15.6	21.3
5.	10.9	10.6	10.4	10.6	10.3	12.4	16.2
6.	12.6	12.3	11.9	11.4	11.0	12.2	16.7
7.	14.9	14.4	14.0	13.2	12.2	12.6	16.1
8.	17.6	17.6	16.5	15.5	14.9	13.5	16.1
9.	20.9	20.3	19.6	18.3	16.2	14.8	16.6
10.	24.9	24.1	23.3	21.8	19.6	16.5	17.3
11.	29.7	28.7	27.8	25.9	22.5	18.7	18.4
12.	35.4	34.3	33.2	30.9	26.6	21.3	19.7
14.	50.3	48.7	47.1	43.9	37.7	28.5	23.4
16.	71.5	69.3	67.0	62.5	53.4	38.8	28.5
18.	101.5	98.3	95.1	88.7	75.9	53.6	35.4
20.	143.8	139.3	134.8	125.8	107.6	74.6	44.7
ρ = 10 days							
1.	15.5	18.6	23.1	33.7	56.0	101.3	192.3
2.	10.6	11.0	11.7	13.9	19.6	31.8	56.9
3.	10.0	10.0	10.1	10.8	13.3	19.6	32.8
4.	10.6	10.4	10.3	10.4	12.6	15.5	24.3
5.	11.7	11.5	11.3	11.0	11.4	13.9	20.4
6.	13.2	12.9	12.6	12.2	11.9	13.4	18.5
7.	15.2	14.8	14.4	13.7	13.0	13.6	17.7
8.	17.5	17.0	16.6	15.7	14.5	14.3	17.4
9.	20.2	19.7	19.2	18.1	16.4	15.4	17.6
10.	23.4	22.8	22.2	21.0	18.8	16.9	18.2
11.	27.2	26.4	25.7	24.3	21.6	18.7	19.0
12.	31.5	30.7	29.8	28.1	24.9	20.9	20.2
14.	42.4	41.3	40.2	37.9	33.4	26.7	23.2
16.	57.1	55.6	54.1	51.0	44.9	34.8	27.5
18.	77.0	74.9	72.8	68.7	60.4	45.9	33.2
20.	103.6	100.8	98.0	92.5	81.4	60.9	40.7
ρ = 14 days							
1.	17.6	21.1	26.3	36.4	63.8	115.4	219.1
2.	11.9	12.3	13.2	15.7	22.1	36.[illegible]	64.[illegible]
3.	11.1	11.1	11.3	12.1	16.9	21.9	36.6
4.	11.5	11.4	11.3	11.5	12.8	17.2	27.0
5.	12.5	12.3	12.1	11.9	12.4	15.2	22.5
6.	13.9	13.7	13.4	13.0	12.8	14.6	20.3
7.	15.7	15.5	15.0	14.4	13.8	14.7	19.1
8.	17.7	17.3	16.9	16.2	15.[illegible]	15.[illegible]	18.7
9.	20.1	19.7	19.2	18.3	16.9	16.1	18.7
10.	22.9	22.4	21.8	20.8	18.9	17.4	19.1
11.	26.1	25.5	24.8	23.6	21.[illegible]	19.6	19.[illegible]
12.	29.7	29.0	28.3	26.9	24.3	[illegible]	20.[illegible]
14.	38.5	37.6	36.7	34.9	31.3	25.[illegible]	23.[illegible]
16.	50.0	48.8	47.6	45.3	40.8	32.[illegible]	27.[illegible]
18.	64.9	63.4	61.8	58.8	52.7	41.[illegible]	32.1
20.	84.3	82.3	80.3	76.3	68.[illegible]	55.7	[illegible]

NOT REPRODUCIBLE

Table A-12 (Cont.)

Days on Pasture	Halftime of Fallout Deposition in Days (ρ)						
	0	.125	.25	.5	1	2	4
ρ = 19 days							
1.	19.3	23.2	29.0	42.3	70.3	127.1	241.4
2.	12.9	13.5	14.4	17.2	24.2	30.4	70.5
3.	12.0	12.0	12.2	13.1	16.3	23.9	40.2
4.	12.3	12.2	12.2	12.4	13.9	18.6	29.3
5.	13.3	13.1	12.9	12.7	13.3	16.4	24.3
6.	14.6	14.3	14.1	13.7	13.6	15.6	21.7
7.	16.2	15.9	15.6	15.0	14.5	15.5	20.4
8.	18.1	17.7	17.4	16.7	15.7	16.0	19.8
9.	20.3	19.9	19.5	18.6	17.3	16.8	19.7
10.	22.8	22.3	21.8	20.9	19.2	18.0	20.0
11.	25.6	25.1	24.5	23.5	21.5	19.4	20.5
12.	28.8	28.2	27.6	26.4	24.1	21.2	21.4
14.	36.5	35.7	34.9	33.4	30.3	25.8	23.8
16.	46.2	45.2	44.3	42.3	38.4	31.8	27.1
18.	58.6	57.3	56.1	53.6	48.6	39.6	31.6
20.	74.3	72.7	71.1	67.9	61.6	49.7	37.3
ρ = 25 days							
1.	20.7	24.9	31.1	45.4	75.5	136.6	259.3
2.	13.8	14.4	15.4	18.4	25.9	42.2	75.5
3.	12.7	12.8	13.0	14.0	17.3	25.5	42.8
4.	13.0	12.9	12.8	13.1	14.7	19.7	31.2
5.	13.8	13.7	13.5	13.4	14.0	17.3	25.7
6.	15.1	14.9	14.6	14.3	14.3	16.4	22.9
7.	16.7	16.4	16.1	15.5	15.1	16.2	21.4
8.	18.5	18.1	17.8	17.1	16.2	16.6	20.7
9.	20.5	20.1	19.7	19.0	17.8	17.4	20.5
10.	22.9	22.4	22.0	21.1	19.6	18.4	20.7
11.	25.5	25.0	24.5	23.5	21.7	19.8	21.1
12.	28.4	27.9	27.3	26.2	24.1	21.5	21.9
14.	35.4	34.7	34.0	32.6	29.9	25.7	24.1
16.	44.1	43.2	42.4	40.6	37.1	31.3	27.2
18.	55.0	53.9	52.8	50.6	46.2	38.4	31.4
20.	68.6	67.2	65.8	63.1	57.6	47.5	36.6
ρ = 32 days							
1.	21.8	26.3	32.8	47.9	79.6	144.0	273.4
2.	14.5	15.1	16.2	19.3	27.3	44.4	79.4
3.	13.3	13.4	13.6	14.3	18.2	26.7	45.0
4.	13.5	13.4	13.4	13.8	15.4	20.6	32.6
5.	14.3	14.1	14.0	13.9	14.6	18.1	26.6
6.	15.5	15.3	15.1	14.7	14.8	17.3	23.6
7.	17.0	16.7	16.5	16.0	15.5	16.8	22.2
8.	18.8	18.4	18.1	17.5	16.7	17.1	21.4
9.	20.8	20.4	20.0	19.3	18.1	17.8	21.1
10.	23.0	22.6	22.1	21.3	19.7	18.8	[illegible]
11.	25.5	25.0	24.5	23.8	21.9	20.2	22.0
12.	28.3	27.7	27.2	26.2	24.2	21.8	22.3
14.	34.6	34.1	33.5	32.2	29.8	25.8	24.4
16.	42.6	42.0	41.2	39.6	36.4	32.0	27.4
18.	52.8	51.8	50.8	48.8	44.8	37.7	31.3
20.	65.1	63.8	62.6	60.1	55.2	[illegible]	36.3

Table A-13. $F_{^{90}Sr}$ values for days between initiation of grazing of contaminated pasture and production of a given milk sample.

Days on Pasture	Halftime of Fallout Deposition in Days (β) 0	.125	.25	.5	1	2	4
ρ = 7 days							
1.	106.8	201.3	346.2	707.1	1549.1	3387.4	7212.6
2.	27.2	30.8	35.9	48.5	73.5	134.5	[illegible]
3.	19.8	20.5	21.7	25.1	34.2	54.2	[illegible]
4.	18.1	18.3	18.6	19.9	24.1	34.8	[illegible]
5.	18.0	18.0	18.0	18.4	20.6	27.3	42.7
6.	18.5	18.4	18.3	18.3	19.4	23.8	35.2
7.	19.4	19.2	19.1	18.8	19.2	22.2	31.0
8.	20.6	20.3	20.1	19.8	19.6	21.5	28.5
9.	21.9	21.7	21.4	21.0	20.4	21.4	27.0
10.	23.5	23.2	22.9	22.4	21.5	21.8	26.2
11.	25.3	25.0	24.7	24.0	22.9	22.5	25.9
12.	27.3	27.0	26.6	25.8	24.5	23.5	26.0
14.	32.0	31.5	31.0	30.1	28.4	26.5	27.0
16.	37.5	36.9	36.4	35.3	33.2	30.0	28.9
18.	44.0	43.4	42.7	41.5	38.9	34.6	31.8
20.	51.7	50.9	50.2	48.7	45.7	40.3	35.1
ρ = 10 days							
1.	152.2	287.8	495.9	1015.6	2231.5	4892.0	10431.4
2.	38.1	43.2	50.5	68.4	107.9	189.4	354.1
3.	27.2	28.3	30.0	34.9	47.5	75.5	133.0
4.	24.4	24.7	25.2	27.1	33.1	47.9	79.5
5.	23.7	23.8	23.9	24.6	27.8	37.0	58.1
6.	23.8	23.8	23.7	23.9	25.5	32.8	47.2
7.	24.4	24.2	24.1	24.1	24.8	29.1	40.9
8.	25.2	25.0	24.9	24.6	24.6	27.7	37.1
9.	26.2	26.0	25.8	25.5	25.3	27.1	34.6
10.	27.5	27.2	27.0	26.6	26.1	27.0	33.1
11.	28.8	28.6	28.3	27.8	27.1	27.3	32.2
12.	30.3	30.1	29.8	29.2	28.3	28.0	31.8
14.	33.8	33.4	33.1	32.5	31.2	29.9	31.9
16.	37.7	37.3	37.0	36.2	34.8	32.6	32.9
18.	42.2	41.8	41.4	40.5	38.8	36.0	34.7
20.	47.3	46.8	46.4	45.4	43.5	40.0	37.2
ρ = 14 days							
1.	212.7	405.0	[illegible]	1426.8	3141.2	6898.7	14726.5
2.	52.7	59.8	69.7	[illegible]	149.7	262.1	491.6
3.	37.2	38.7	41.1	47.9	65.4	103.9	183.1
4.	32.8	33.4	34.1	36.7	45.2	65.3	108.7
5.	31.4	31.6	31.8	32.9	37.3	50.0	[illegible]
6.	31.0	31.1	31.1	31.5	34.0	42.5	63.3
7.	31.2	31.2	31.2	31.7	32.5	38.4	54.5
8.	31.8	31.7	[illegible]	31.5	32.0	[illegible]	[illegible]
9.	32.5	32.4	32.3	[illegible]	[illegible]	[illegible]	[illegible]
10.	33.5	33.3	33.1	[illegible]	[illegible]	[illegible]	[illegible]
11.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12.	35.8	35.5	35.3	[illegible]	[illegible]	[illegible]	[illegible]
14.	[illegible]	[illegible]	[illegible]	37.5	[illegible]	[illegible]	[illegible]
16.	41.8	41.3	41.0	[illegible]	[illegible]	[illegible]	[illegible]
18.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table A-13 (Cont.)

Days on Pasture	Halftime of Fallout Deposition in Days (β)						
	0	.125	.25	.5	1	2	4
ρ = 19 days							
1.	288.2	546.8	944.6	1940.5	4277.6	9402.8	20694.0
2.	70.9	80.5	94.2	127.8	201.9	354.7	663.5
3.	49.5	51.7	54.9	64.1	87.7	139.4	245.8
4.	43.4	44.1	45.2	48.8	59.0	87.1	145.0
5.	41.1	41.4	41.8	43.3	49.3	66.2	104.3
6.	40.2	40.3	40.4	41.1	44.5	55.6	83.4
7.	40.0	40.0	40.0	40.3	42.1	50.1	71.2
8.	40.2	40.2	40.1	40.2	41.1	46.7	63.4
9.	40.8	40.6	40.6	40.4	40.8	44.7	58.1
10.	41.5	41.3	41.2	41.0	41.0	43.8	54.5
11.	42.3	42.2	42.0	41.7	41.4	43.1	52.0
12.	43.3	43.1	42.9	42.6	42.1	43.0	50.3
14.	45.5	45.3	45.1	44.7	44.0	43.7	48.4
16.	48.0	47.8	47.5	47.1	46.2	45.2	47.9
18.	50.8	50.5	50.3	49.8	48.8	47.3	48.4
20.	53.8	53.5	53.3	52.7	51.6	49.7	49.5
ρ = 20 days							
1.	378.7	719.3	1243.4	2556.5	5640.4	12409.4	26542.1
2.	92.7	105.4	123.4	167.4	264.4	464.8	869.1
3.	64.4	67.3	71.5	83.6	114.4	182.0	321.0
4.	56.1	57.1	58.6	63.5	77.8	113.2	188.6
5.	52.7	53.1	53.8	55.9	63.7	85.7	135.1
6.	51.2	51.4	51.7	52.6	57.1	71.9	107.6
7.	50.6	50.7	50.8	51.2	53.8	64.1	91.4
8.	50.5	50.5	50.5	50.7	52.1	59.4	80.9
9.	50.8	50.7	50.7	50.7	51.4	56.5	73.9
10.	51.3	51.2	51.1	51.0	51.2	54.8	69.0
11.	51.9	51.8	51.7	51.5	51.4	53.8	65.5
12.	52.7	52.5	52.4	52.1	51.9	53.4	62.3
14.	54.5	54.3	54.2	53.8	53.3	53.5	59.0
16.	56.6	56.4	56.2	55.9	55.1	54.6	58.6
18.	59.0	58.8	58.6	58.1	57.3	55.2	58.4
20.	61.5	61.3	61.1	60.6	59.7	56.2	58.9
ρ = 32 days							
1.	464.2	920.3	1591.5	3274.2	7229.0	15912.6	34075.5
2.	118.1	134.3	157.6	213.6	337.8	593.0	1108.9
3.	81.7	85.5	90.9	106.3	145.5	231.6	406.6
4.	70.8	72.2	74.1	80.2	95.7	143.7	239.5
5.	66.2	66.9	67.7	70.5	80.5	108.4	171.1
6.	64.0	64.3	64.8	65.1	71.6	90.6	135.8
7.	63.0	63.1	63.3	64.0	67.3	80.5	114.9
8.	62.6	62.6	62.7	63.0	64.9	74.3	101.3
9.	62.5	62.5	62.5	62.6	63.7	70.4	[illegible]
10.	62.8	62.7	62.7	62.7	63.2	68.0	85.9
11.	63.3	63.2	63.1	63.0	63.1	66.4	81.2
12.	63.9	63.7	63.6	63.5	63.3	65.6	77.6
14.	65.4	65.2	65.1	64.8	64.4	65.1	73.4
16.	67.2	67.0	66.8	66.5	65.9	65.7	71.2
18.	69.2	69.0	[illegible]	68.5	[illegible]	[illegible]	[illegible]
20.	71.4	71.2	[illegible]	70.6	69.8	[illegible]	[illegible]

Table A-14. $F_{^{137}Cs}$ values for days between initiation of grazing of contaminated pasture and production of a given milk sample.

Days on Pasture	Halftime of Fallout Deposition in Days (β) 0	.125	.25	.5	1	2	4
ρ = 7 days							
1.	64.9	92.0	127.7	204.6	362.3	680.2	1517.2
2.	28.4	30.9	34.5	44.1	65.1	111.9	254.8
3.	22.5	23.2	24.1	27.2	35.8	54.6	94.7
4.	20.9	21.1	21.4	22.6	26.6	37.7	61.5
5.	20.7	20.7	20.7	21.1	23.4	30.4	46.8
6.	21.1	21.0	21.0	21.0	22.1	26.8	39.1
7.	22.0	21.8	21.6	21.5	21.8	25.0	34.6
8.	23.1	22.6	22.6	22.3	22.2	24.2	31.9
9.	24.4	24.1	23.9	23.4	22.9	24.1	30.2
10.	25.9	25.6	25.3	24.8	24.0	24.4	29.3
11.	27.5	27.2	26.9	26.3	25.3	25.0	28.6
12.	29.4	29.0	28.7	28.0	26.8	25.9	28.8
14.	33.5	33.2	32.8	32.0	30.4	28.5	29.5
16.	38.8	38.1	37.6	36.7	34.8	31.9	31.2
18.	44.4	43.8	43.3	42.1	39.1	35.2	33.6
20.	51.1	50.5	49.8	48.5	45.0	41.2	36.6
ρ = 10 days							
1.	91.9	130.5	181.2	290.4	514.5	966.0	1870.6
2.	39.6	43.1	48.4	61.9	92.7	157.2	287.8
3.	30.8	31.8	33.2	37.6	49.4	76.1	151.5
4.	28.0	28.3	28.9	30.6	36.5	51.6	84.3
5.	27.1	27.2	27.4	28.1	31.3	41.0	63.4
6.	27.1	27.0	27.1	27.3	29.0	35.6	52.2
7.	27.5	27.4	27.3	27.3	28.1	32.7	45.6
8.	28.2	28.1	27.9	27.8	28.0	31.1	41.4
9.	29.1	29.0	28.8	28.5	28.3	30.4	38.7
10.	30.2	30.0	29.8	29.4	29.0	30.2	36.9
11.	31.4	31.2	31.0	30.6	29.9	30.4	35.8
12.	32.8	32.6	32.3	31.8	31.0	30.9	35.1
14.	35.9	35.6	35.3	34.7	33.7	32.6	34.9
16.	39.5	39.1	38.6	38.1	36.8	35.0	35.7
18.	43.5	43.2	42.8	42.0	40.5	38.0	37.2
20.	48.1	47.7	47.3	46.4	44.7	41.7	39.4
ρ = 14 days							
1.	127.8	181.6	252.5	408.6	717.3	1346.8	[illegible]
2.	54.5	59.5	68.8	[illegible]	128.3	217.6	395.5
3.	41.8	43.3	45.7	51.4	67.7	104.4	180.7
4.	37.5	36.1	38.9	41.6	49.5	70.2	114.9
5.	35.8	36.0	36.3	37.5	42.0	55.2	85.6
6.	35.2	35.3	35.4	35.9	38.4	47.5	69.7
7.	35.2	35.2	35.2	35.3	36.7	43.1	60.4
8.	35.5	35.5	35.4	35.4	[illegible]	40.5	54.3
9.	36.1	36.0	35.9	35.8	[illegible]	39.0	50.2
10.	36.9	36.7	36.6	36.4	[illegible]	38.2	[illegible]
11.	37.8	37.6	37.5	37.2	36.6	[illegible]	45.4
12.	[illegible]	[illegible]	[illegible]	38.1	[illegible]	38.1	[illegible]
14.	41.1	40.9	40.7	40.3	39.5	39.0	42.8
16.	43.9	43.6	43.3	[illegible]	41.9	40.7	42.7
18.	46.9	46.6	46.3	45.3	44.7	[illegible]	[illegible]
20.	50.3	50.0	49.7	[illegible]	[illegible]	45.7	[illegible]

Table A-14 (Cont.)

Days on Pasture	Halftime of Fallout Deposition in Days (β) 0	.125	.25	.5	1	2	4
ρ = 19 days							
1.	172.8	245.8	341.6	547.7	970.5	1622.4	3529.2
2.	73.1	79.9	89.8	115.1	172.7	295.9	556.7
3.	55.7	57.7	60.5	66.7	96.6	159.[illegible]	2[illegible].1
4.	49.5	50.3	51.4	54.8	65.8	93.5	155.[illegible]
5.	46.7	47.1	47.6	49.2	55.4	73.6	115.4
6.	45.5	45.6	45.9	46.7	50.2	62.3	92.0
7.	45.0	45.1	45.1	45.5	47.6	56.1	79.0
8.	45.0	44.9	45.0	45.1	46.2	52.3	70.5
9.	45.2	45.2	45.1	45.1	45.6	49.9	64.7
10.	45.7	45.6	45.5	45.4	45.6	48.5	60.4
11.	46.3	46.2	46.1	45.9	45.8	47.8	57.7
12.	47.0	46.9	46.8	46.5	46.2	47.4	55.6
14.	48.8	48.6	48.5	48.2	47.6	47.7	53.1
16.	50.9	50.7	50.5	50.1	49.4	48.[illegible]	52.1
18.	53.3	53.1	52.9	52.5	51.6	50.5	52.1
20.	56.0	55.8	55.5	55.0	54.1	52.6	52.9
ρ = 20 days							
1.	226.6	322.6	448.3	713.0	1274.1	2392.5	4533.6
2.	95.4	104.4	117.3	150.6	226.0	383.[illegible]	702.4
3.	72.3	74.9	78.6	89.4	118.0	182.4	315.8
4.	63.8	64.9	66.4	71.0	85.4	121.3	198.6
5.	59.9	60.4	61.1	63.3	71.4	94.4	146.7
6.	57.9	58.1	58.5	59.7	64.4	80.1	118.5
7.	56.8	57.0	57.2	57.8	60.6	71.7	101.3
8.	56.4	56.5	56.5	56.4	58.5	66.5	90.0
9.	56.3	56.3	56.3	56.5	57.4	63.2	82.2
10.	56.5	56.4	56.4	56.4	56.9	61.6	76.6
11.	56.8	56.8	56.7	56.6	56.6	59.7	72.5
12.	57.3	57.2	57.1	57.0	56.9	58.9	68.5
14.	58.6	58.5	58.4	58.1	57.8	58.4	65.7
16.	60.3	60.1	60.0	59.7	59.1	59.0	63.7
18.	62.2	62.0	61.8	61.5	60.8	60.1	63.6
20.	64.4	64.2	64.0	63.6	62.8	61.7	63.1
ρ = 32 days							
1.	289.4	412.1	572.8	914.6	1627.9	3058.9	5920.3
2.	121.4	132.9	149.5	191.9	288.[illegible]	488.9	895.6
3.	91.6	95.6	99.[illegible]	115.6	150.3	231.9	401.6
4.	80.5	82.0	85.9	89.8	108.2	153.6	252.2
5.	75.2	75.9	76.9	79.8	90.1	119.3	1[illegible]5.6
6.	72.3	72.8	73.3	74.8	80.9	100.9	1[illegible].6
7.	70.7	71.0	71.3	72.1	75.8	90.[illegible]	127.3
8.	69.8	69.9	70.1	70.6	72.9	83.1	112.7
9.	69.4	69.4	69.5	69.6	71.2	78.[illegible]	1[illegible]
10.	69.2	69.2	69.2	69.4	70.2	75.[illegible]	95.3
11.	69.3	69.2	69.2	69.3	69.7	73.[illegible]	[illegible]
12.	69.5	69.5	69.4	69.4	69.[illegible]	72.5	85.[illegible]
14.	70.4	70.3	70.2	70.0	69.[illegible]	71.1	80.5
16.	71.6	71.5	71.4	71.1	70.8	71.1	77.5
18.	73.2	73.0	72.[illegible]	72.[illegible]	72.[illegible]	71.[illegible]	75.[illegible]
20.	75.9	75.8	74.6	74.3	73.7	72.[illegible]	75.[illegible]

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13. ABSTRACT

Experimental verification of a method for the prediction of the total intake commitment of ^{137}Cs, ^{90}Sr and ^{131}I from milk by average members of a human population following deposition of fallout on pasture is presented. The method has been expanded to account for extended and multiple depositions and delays in pasturing cows. As a dietary countermeasure against radio-strontium secretion into milk sodium alginate was about twice as effective as aluminum phosphate gel. Ferric ferrocyanide fed to cows produced over a [illegible]% reduction in ^{137}Cs in milk.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Radiostrontium						
Radioiodine						
Radiocesium						
Radiocontamination of Milk						
Predicted Radionuclide Intake						
Countermeasure Effectiveness						
Sodium Alginate						
Prussian Blue						
Ferric Ferrocyanide						
Aluminum Phosphate gel						